Journal of Experimental Psychology

Journal of
Experimental Psychology

VOL. I, No. 3. JUNE, 1916

THE HIPP CHRONOSCOPE: ITS USE AND ADJUSTMENT

BY A. T. POFFENBERGER, JR., AND J. J. B. MORGAN

Columbia University

In an article entitled 'The Hipp Chronoscope without Armature Springs,'[1] Knight Dunlap describes an ingenious means of getting accurate time records with the Hipp chronoscope. The present paper is the report of a rigid test of the method, carried on during a period of six months. The writers feel that a detailed account of the tests and of the arrangement of the apparatus for them will be appreciated by owners of the Hipp chronoscope. Special attention will be given to the actual chronoscope adjustments required.

The method as described by Dunlap is essentially as follows: Current is taken from the ordinary commercial circuit (direct current), and passed through a bank of incandescent lamps (three 16-c.p. 60-watt, arranged in parallel). The two terminals are connected by a shunt circuit containing a rheostat. Two circuits are then taken from this source, one to each pair of the electromagnets of the chronoscope. The springs attached to the chronoscope armature are removed and the clutch shaft is so balanced that the shaft will stay in clutch as well as out of clutch. This is done by increasing the size of the counterweight previously used for balancing.[2] The upper magnet circuit includes the stimulus

[1] *Brit. J. of Psychol.*, 1912, *5*, 1–7.

[2] The chronoscope might well be modified so as to make this change in the counterweight unnecessary. Dunlap states that such a modification is being worked out by him, but those who own the instrument in its present form will have to resort to a change in the counterweight.

key and the lower one the reaction key. When reaction time is to be measured, both circuits are closed and the armature is held against the upper magnets. Since both magnets are acting, the armature might be drawn to the upper or lower set of magnets depending on which circuit is closed first, that is, the clock might or might not be recording. The proper position of the armature, namely, against the upper magnets, may be obtained by opening the reaction key (controlling the circuit through the lower magnets) for a moment, thus allowing the upper magnets to draw the armature up. When in this position, the lower circuit may again be closed without changing the position of the armature. When the stimulus is given, the upper circuit is broken and the lower magnets pull the armature down, throwing the clutch into the moving gears and putting the chronoscope hands in motion. The circuit through the upper magnets is again closed (after an interval ranging from 20 to 73 sigma). This does not change the position of the armature which is against the lower magnets, since the upper magnets cannot overcome the force of attraction of the lower magnets, the two currents being equal. The subject reacts by opening the circuit through the lower magnets, thus allowing the upper magnets to draw the armature up. This movement throws the shaft out of clutch, and the hands stop. The current through the upper magnets thus takes the place of the armature springs.

Dunlap suggests the use of a simple relay for closing the upper circuit, about 50 sigma after it is opened. Thus arranged, the key, which gives the stimulus and opens the circuit through the upper magnets of the chronoscope, may be made to open (or close) the circuit through the electromagnets of a relay. The armature of the relay when released (or attracted, if the relay circuit is closed), will again make the circuit through the upper magnets. This set of magnets is now ready to draw the chronoscope armature up as soon as it is released from the lower pair of magnets. The arrangement of the two circuits may be represented schematically as in Fig. 1. Dunlap used a Wundt hammer for testing the chronoscope and hence the falling hammer broke and made the different circuits instead of the experimenter and subject.

As Dunlap states, the method does away with one great source of variation, namely, that due to the effect of temperature changes and age upon the springs. It also permits a relatively large variation in the current strength, if the mechanism is properly adjusted. The matter of current strength is the more important factor since it would make

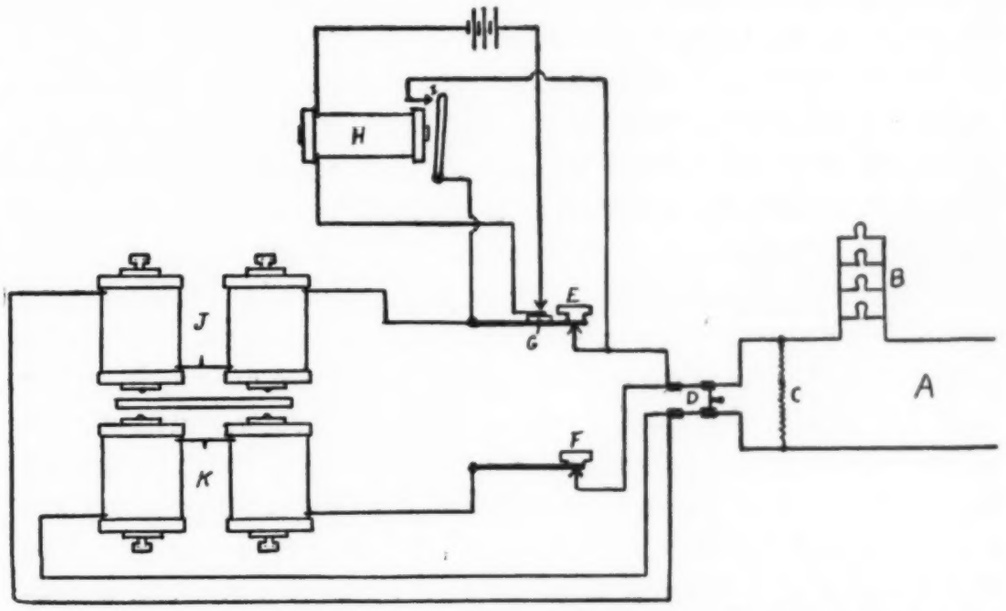


FIG. 1. Schematic Arrangement of the Chronoscope Circuits. *A*. Source of current supply from the ordinary light circuit. *B*. Lamp resistance, which reduces the 116-volt circuit to the desired strength. *C*. Shunt circuit, connecting the two sides of the circuit, and acting as a kind of safety valve for the escape of current beyond the desired strength. *D*. Switch connecting the chronoscope circuits with the main circuit. *E*. Experimenter's key, inserted in the circuit containing the upper magnets of the chronoscope. Stimulus is given by release of this key. *F*. Subject's key, inserted in the circuit containing the lower magnets of the chronoscope. Reaction is made by release of this key. *G*. Insulating block to keep the relay circuit insulated from the chronoscope circuit. *H*. Relay to close the chronoscope circuit through contact *I*, after the stimulus is given. The breaking of the chronoscope circuit makes the circuit through the relay magnet *H*, which in turn by reacting on the armature closes the upper magnet circuit after a brief interval. *J*. Upper magnets of the chronoscope. *K*. Lower magnets of the chronoscope.

unnecessary the use of storage or gravity batteries and eliminate the constant control testing previously made necessary by the slight changes in the current.

The value of Dunlap's method depends upon the following assumptions, the first three of which were clearly stated by him:

1. That the two sets of electro-magnets are nearly alike in windings and cores.

2. That the current through the two sets of magnets is equal.

3. That the chronoscope is properly adjusted.

4. That the current acts upon the two magnets for approximately the same length of time, or that this difference in time has no appreciable effect.

Upon the first and the fourth depends the absence or equality of the latent times of the two magnets, and the equality of the retardation due to the magnetization of the magnet cores. By the common method of using the chronoscope with its springs, the latent time of the one set of magnets was offset by the action of the spring against it. This spring could be adjusted for a given current strength. But any changes in the tension of the spring or in the strength of the current would change the time of chronoscope, until a new adjustment should be made. Changes in the current strength in the one set of magnets according to Dunlap's method are accompanied by corresponding changes in the other. And the force is not exerted against any tension since the armature is balanced and the one magnet never moves it until the other magnet has released it.

Upon the first three conditions and especially upon the third (as will later appear) depends the equality in the actual force exerted by the two sets of magnets.

These four conditions will be discussed in detail.

1. The Equality of Windings and Cores in the Two Sets of Magnets

The equality of the windings and cores is assumed in the original construction of the chronoscope. The resistance offered by the two sets of magnets in the chronoscope in this work was found to be exactly the same. The following seems to be a good test for the equality of the magnet cores, on the assumption that any differences would appear in the different amounts of residual magnetism of the two sets of cores. The armature is first perfectly balanced by adjusting

the counterweight, after the apparatus has stood idle for several days to insure absence of residual magnetism. Equal currents are then passed through both sets of magnets and at various intervals the balance is again tested. If the cores are alike, the balance should not be disturbed, but if one has a greater tendency to retain magnetism than the other, then the balance will be disturbed. This test made upon our chronoscope showed that when the current passed through both sets of magnets for two minutes the armature came to a position of rest against the lower magnets. This would indicate greater residual magnetism in the cores of the lower magnets. This conclusion was supported by the fact that the balance could be restored by reversing the current through the lower magnets for about one second. Reversing the current through the upper magnets did not restore the balance.

The influence of this factor upon accurate time records is shown by the following readings:

Normal reading	200.1	sigma	A.D. *0.4*
Current through upper magnets only for 10 min.	200.2	"	" *0.6*
Current through lower magnets only for 10 min.	201.0	"	" *0.4*

When the current passed through the upper magnets alone for 10 minutes, the average for 10 readings was 200.2 sigma, and when passed through the lower magnets for 10 minutes the average was 201.0 sigma. This difference of 0.8 sigma is practically covered by the probable error of the difference (0.6). It is clear that for short periods of time small differences in the cores need not be considered.[1]

2. The Equality of the Currents in the Two Sets of Magnets

The arrangement of the circuits as reported by Dunlap insures the equality of the two currents provided there is no great difference of resistance in the two circuits. Both circuits are taken from the same current source. The shunt

[1] It might be well to mention that the two sets of magnets on our chronoscope were taken from two chronoscopes of the same pattern. One of the original pair had been rewound to correct errors arising from the common method of using the instrument.

circuit containing a rheostat set for a constant resistance as mentioned above, serves to reduce the effect of changes upon the chronoscope circuit of changes in the current source.

Conditions 1 and 2 being fulfilled, the latent time of the two magnets is no longer a factor to be reckoned with. That is, the latent time of the one would be balanced by the latent time of the other. A weak current would make a long latent time for each set of magnets, and a strong current would make a short latent time for each set. In the use of the springs, however, the spring tension would be constant as compared with the latent times which vary with the current strength.

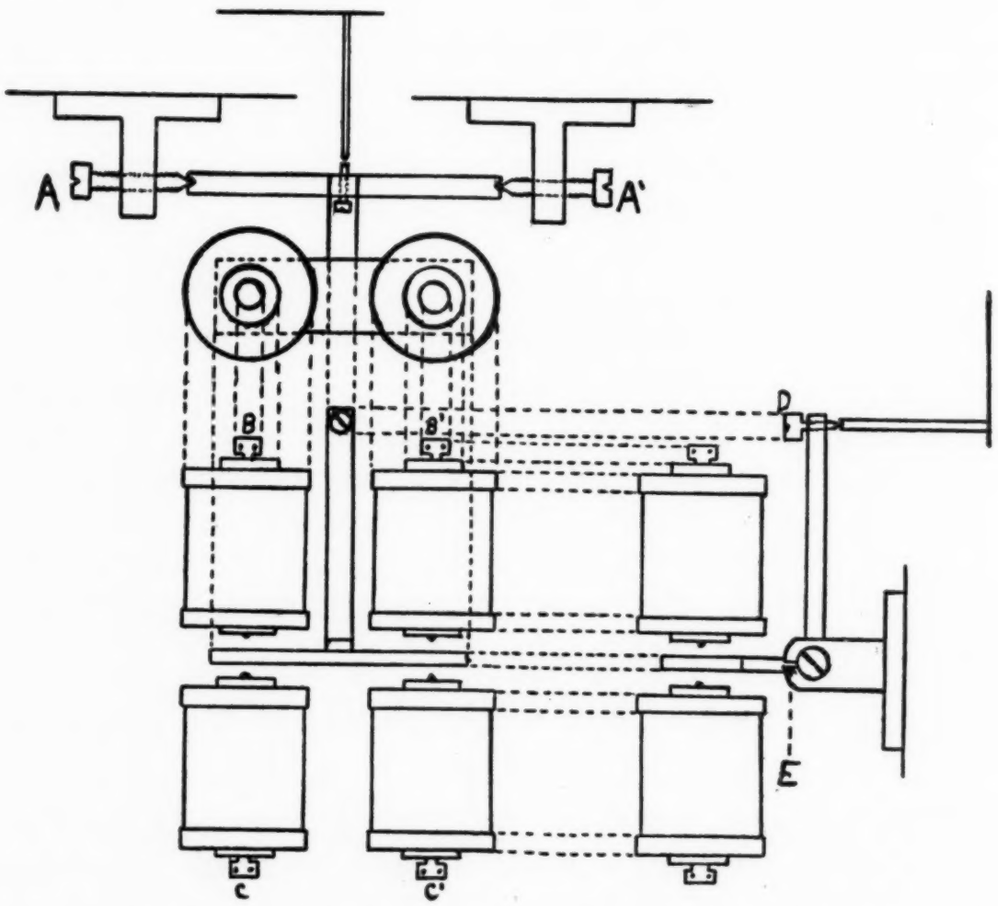


FIG. 2. Front, Top and Side Views of the Mechanism of the Chronoscope. *AA'*. Bearings of Armature Lever. *BB'* and *CC'*. Pins passing through the cores of the magnets and adjustable in position. *D*. Bearing of clutch shaft. This adjustment must be used to compensate for adjustment of pins *BB'* and *CC'*. *E*. Showing how bearing pins of the armature lever *A* and *A'* are kept in adjustment.

3. The Proper Adjustment of the Chronoscope

After the first two sets of conditions were fulfilled and the chronoscope was apparently adjusted, it was found that, when both circuits were closed, the upper magnets always drew the armature away from the lower ones. Then it was noted that the armature did not move equally close to the upper and lower magnets, and that this was just as important a factor as the strength of the current in the two magnets.

This distance it will be seen by referring to Fig. 2 is regulated by the pins *BB'* and *CC'* which pass through and project from the face of the core of each magnet. An attempt to vary the position of these pins showed at once the extreme delicacy of this adjustment and its importance for the proper regulation of the chronoscope. No matter how exactly the two currents may be adjusted, a change in the position of these pins, almost too small to be perceived by the unaided eye, will affect the time, especially where there is any variation in the currents. This will be demonstrated later. Two other adjustments are possible, the importance of which are likely to be overlooked; first, the two screws forming the bearings of the lever, one arm of which is the armature (represented in Fig. 2 by *A* and *A'*); second, the screw (marked *D* in the figure), which regulates the movement of the clutch shaft with relation to the armature lever.

A. The Adjustment of Screws A and A'

Allowing the screws *A* and *A'* to work loose from the vibration of the apparatus caused a change in the average time record of about 6 sigma as shown from the figures in Table I. Each figure is an average of 10 records and is accompanied by its average deviation. In the chronoscope used in this work, these screws gradually worked loose,

Table I

	Av.	A.D.
Screws *AA'* properly adjusted	200.0	*0.8*
" " loosened	194.3	*1.1*
" " readjusted	200.3	*0.7*

although they are supposed to be firmly held in position by the split socket. (See *E* in Fig. 2.) When properly adjusted these screws were permanently fastened by pinching the sides of the socket more closely together and covering the screw with shellac.

B. The Effect of Changing the Position of Pins BB′ and CC′

The effect of changing the pins *BB′* and *CC′* may be seen from Table II. In our instrument these pins also were somewhat loose and seemed likely to change their position. After adjustment they were shellaced to prevent movement. The figures in the table represent averages of 10 reactions. They are followed by their average deviations. The changes in the position of the pins are expressed in terms of fractions of a turn of the screw which is the upper part of the pin. An inspection of these figures will show how great a change in

TABLE II

	Av.	A.D.
Before changing position of pins	200.3	0.7
Lowering *C* and *C′* 1/8 turn	202.3	0.4
Raising *C* and *C′* 1/8 turn	200.7	0.8
" *B* " *B′* 1/6 "	199.5	0.8
" *C* only 1/12 "	198.3	0.7
" *C* and *C′* 1/12 "	198.1	0.7

the time a slight change in the position of these pins makes.

C. The Adjustment of Screw D

The adjustment of screw *D* must follow that of the pins *BB′* and *CC′*, since by that means the clutch can be properly meshed, after the range of movement has been limited by the pins.

D. A Proposed Method of Testing the Accuracy of Adjustment

The assumption made by Dunlap is that if the chronoscope is properly adjusted, ordinary changes in the current will not affect the time. This being theoretically true, it follows that any changes in the current strength which are accompanied by a variation in the time will indicate that the

instrument is not properly adjusted. And further, the nature of the required adjustment can be determined from the direction of the time variation. Hence it occurred to the writers that changes in time as a result of controlled variation of the current strength might serve as a measure of accuracy of chronoscope adjustment.[1] Table III. shows the records obtained by applying this test.

[1] This test is based on the law that the attracting or repelling force exerted by a magnet at any point in the magnetic field is inversely proportional to the square of the distance from the pole. Now if the pins *BB'* and *CC'* are properly set, when the armature is against the pins of the lower magnets, it will be the same distance from the poles of the upper magnet as it will be from the poles of the lower magnets when it is against the pins of the upper. Therefore, according to the law just stated, the force exerted upon the armature by either set of magnets will be equal. And further the time of movement of the armature will be the same in the one direction as in the other.

Now suppose that the pins were so set that when the armature is down, it is farther from the poles of the upper magnet than it is from the poles of the lower magnets when it is against the pins in the upper magnet. This would make a difference in the relative force exerted by each set of magnets inversely proportional to the squares of the distances from each. In order to give a concrete case, let us suppose that this difference was 0.1 mm., allowing 2 mm. for the thickness of the armature and supposing the total distance that it could move to be 1 mm. The distance of the center of the armature from the two poles when in the two positions against the pins would be 2.2 mm. and 2.1 mm. respectively. This allows for the projection of the pins past the poles of the magnets, a minimum distance of 0.1 mm. Then according to the law of inverse squares, the force of the two poles would be as 1 is to 1.0974.

$$\frac{\text{Distance when at pins } BB' \text{ to lower poles}}{\text{Distance when at pins } CC' \text{ to upper poles}} = \frac{(2.2)^2}{(2.1)^2} = \frac{4.84}{4.41} = \frac{1.0974}{1}$$

Knowing the relative force exerted upon the armature at each position, by the application of the law of acceleration, we can ascertain what difference in time such a difference in force would make. We can also determine the differences when different strengths of current are used. Without going into details to determine the force of the magnets, let us suppose for our purpose that the forces with the different currents used are such as to cause accelerations of 4, 6, and 8 cm. per sigma.

Since with the assumed difference of movement the relative force of the magnets upon the armature in the two positions is as 1 to 1.0974, the relative accelerations of the armature with the three currents would be:

	Upward movement	Downward movement
Weak current strength	4	4.3896
Medium current strength	6	6.5844
Strong current strength	8	8.7792

Applying the formula for acceleration (which is that the distance is equal to one half of the acceleration multiplied by the square of the time, Dis. $= \frac{1}{2} at^2$) we obtain the times for the different strengths of current as follows, keeping in mind that the total distance to be moved is 1 mm.

TABLE III

Changes in Adjustment	Resistance					
	1 Lamp		2 Lamps		3 Lamps	
	Av.	A.D.	Av.	A.D.	Av.	A.D.
Original reading	202.8	*1.3*	200.3	*0.7*	199.0	*0.6*
Lowering *CC'* 1/8 turn	205.0	*1.4*	202.3	*0.4*	196.5	*1.4*
Raising *CC'* 1/8 turn and Raising *BB'* 1/12 turn	202.9	*1.2*	200.7	*0.8*	197.3	*0.8*
Raising *B* only 1/12 turn	201.6	*1.0*	200.8	*0.2*	197.5	*0.5*
Raising *BB'* 1/12 turn	200.5	*1.1*	199.5	*0.7*	197.5	*1.5*
Raising *C* only 1/12 turn	197.3	*0.9*	198.3	*0.7*	196.4	*1.0*
Raising *CC'* 1/12 turn	196.1	*0.9*	198.1	*0.7*	196.4	*0.8*

Each figure in this table is the average of 10 trials. The first column shows the changes that were made in the position of the pins. The next three columns show the

	Upward Movement	Downward Movement	Difference
Weak current	$1.0 = 2t^2$ $t = 0.707$ sec.	$1.0 = 2.1948t^2$ $t = 0.675$ sec.	0.032 sec.
Medium current	$1.0 = 3t^2$ $t = 0.577$ sec.	$1.0 = 3.2922t^2$ $t = 0.551$ sec.	0.026 "
Strong current	$1.0 = 4t^2$ $t = 0.500$ sec.	$1.0 = 4.3896t^2$ $t = 0.477$ sec.	0.023 "

The difference between the time of the upward and downward movements for the weak, medium and strong currents is respectively 0.032, 0.026 and 0.023 seconds. The upward movement is slower than the downward movement in every case. But the stronger the current the less the difference. This shows the advantage of a fairly strong current to escape the effects of slight misadjustment. If we work out the time values for a greater difference in adjustment, *e. g.*, 0.3 mm. instead of 0.1 mm., we get the following:

	Upward Movement	Downward Movement	Difference
Weak current	0.707 sec.	0.618 sec.	0.089 sec.
Medium current	0.577 "	0.505 "	0.072 "
Strong current	0.500 "	0.437 "	0.063 "

This shows that the greater the misadjustment, the greater will be the divergence of the readings with the different current strengths.

Consider now the records of actual chronoscope tests after the adjustments had been made as accurately as possible. The three current strengths consisted of the regular light circuit with one 16-c.p. lamp in circuit (the weakest current), two 16-c.p. lamps in parallel (the medium strength current), and three 16-c.p. lamps in parallel (the strongest current). The weak current gave a reading of the chronoscope of 202.8 sigma as an average of 10 readings; the medium current gave a reading of 200.3 sigma, and the strong current gave a reading of 199.0 sigma. This shows that the pins

readings with one, two and three lamp resistances. The changes in the position of the screws *BB'* and *CC'* indicated by the fraction of a turn, are only approximate, although the extent of the movement was judged as accurately as possible by the eye. A comparison of the readings in the three columns shows that the times were closer together or farther apart as a result of the change in position of the pins.

It will be noted that in the final record there is still a difference of about 2 sigma between the two lamp reading and the one and three lamp reading, also that the general average is somewhat below 200 sigma which is the standard time. This was found to be due to the fact that the changes in the position of the pins required a compensating adjustment of the counterweight. When the armature had again been perfectly balanced, the following readings were obtained:

1 Lamp[1]		2 Lamps		3 Lamps	
Av. 198.4	A.D. *0.4*	Av. 200.1	A.D. *0.3*	Av. 198.8	A.D. *0.6*

The above readings are about as close as one can get with the present means of adjusting the counterweight and

were now so set as to give the same situation as shown in the theoretical case above, *i. e.*, that when down the armature was farther from the poles of the upper magnets than it was from the poles of the lower magnets when up. Experimenting confirmed this, for lowering the pins in the lower magnets, thus increasing the difference still more, gave the following readings: weak current 205.0 sigma, medium current 202.0 sigma, and strong current 196.0 sigma. Raising the lower pins again gave readings similar to those obtained in the first instance. A complete series of such readings taken as adjustments were made is shown in Table III. It will be seen that changes in the positions of the pins were so slight that accurate adjustments would be impossible without the aid of some test such as this.

To use the test for accuracy of adjustment, one need not follow the theory of the matter. All that is needed after the currents in the electro-magnets have been made equal, is to alter the current strengths, affecting both circuits alike and take readings with each change. If the readings differ, the pins of one pair of magnets may be changed. If this makes the readings more diverse, it will be seen that the wrong movement was made and the succeeding adjustments can then be made in the right direction.

[1] Here it will be noted that the one-lamp reading has dropped slightly below the two-lamp reading, leaving the time longer for the two-lamp resistance than for either one or three lamps. The same thing may be noted in the last two changes in Table III., where only one pin was changed at a time. The writers are unable to account for this change unless it be due to slight differences in the position of *C* with relation to *C'* or *B* with relation to *B'*. As it occurred only when the three readings came very close together, it does not reduce the accuracy of the method, and has only a theoretical interest.

moving the pins. A more severe test of the adjustment of the chronoscope was made by changing the resistance at each reading over a range of from one to three lamps, in a continuous series of 25 readings. The results of the test are shown in Table IV. The first and third columns represent the number of lamps resistance, and the second and fourth columns the individual readings of the chronoscope. Below is the average of these readings with its average deviation. The changes of current in this test are greater than the fluctuations of an ordinary commercial circuit. The results

TABLE IV

Resistance	Readings	Resistance	Readings
3	198	2	200
2	198	3	199
1	197	2	200
2	200	1	196
3	199	2	201
2	200	1	197
1	198	3	199
3	198	2	200
2	199	1	196
1	197	3	199
2	200	1	196
3	198	3	198
		1	196
			Av. 198.4 A.D. *1.2*

of this test seem to give ample proof of the value of Dunlap's method of using the Hipp chronoscope.

4. That the Current Acts Upon the Two Sets of Magnets for Approximately the Same Length of Time, or That This Difference Has No Appreciable Effect

After the chronoscope had been adjusted by the method described under 3, the current was sent through each set of magnets separately and for periods varying in length. When the current was allowed to flow continuously through the upper magnet only, for ten minutes, there was no change in the standard time. When the same procedure was followed for the lower magnets the time was increased about 0.8 sigma with a P. E. of 0.6.

This shows that a cumulative difference of 10 minutes or less between the times the current acts upon the two sets of magnets makes no difference in the chronoscope record. In the ordinary reaction time procedure, such a cumulative difference would not occur, on account of the intervals between measurements.

The Wundt Hammer as a Control Instrument

The foregoing tests were made with the Cattell gravity chronometer, which has been described in several reports.[1] However, as most laboratories are equipped with the Wundt hammer, a number of readings were taken to determine the reliability of this instrument for control purposes. In order to adapt it to Dunlap's method, the hammer was used as follows: The electro-magnet of the hammer was controlled by a separate circuit. The circuit containing the upper magnets of the chronoscope passed through the core of this electro-magnet to the arm of the hammer. An additional binding post was attached to the hammer at its fulcrum. This circuit was broken as soon as the hammer head was released from the core of the magnet, and the chronoscope began to record at this point. The upper key on the Wundt hammer was set so as to be *made* about the middle of the hammer's fall, and served to remake the circuit through the upper magnets as required by Dunlap's method. This key was changed to a mercury contact key on account of the uncertainty of action of the original contact. The circuit through the lower chronoscope magnets included the break key at the base of the hammer. The readings taken with the instrument thus arranged are given in Table V.

The apparatus is not as satisfactory as the more cumbersome types of control, but with care might be used as a test for ordinary reaction times. This method of wiring which would eliminate the inaccuracies attributed to the upper contact of the hammer probably accounts for an accuracy greater than that usually reported with the use of this apparatus.

[1] Cattell's original description of the apparatus appeared in *Memoirs of the Nat. Acad. of Sciences*, 7, 1893.

TABLE V

	Av.	A.D.
1st 10 readings	199.8	*1.4*
2d " "	198.8	*1.2*
3d " "	198.2	*0.8*
4th " "	199.3	*1.1*
5th " "	198.5	*1.1*
6th " "	197.6	*0.6*
7th " "	198.0	*0.6*
8th " "	199.0	*1.4*
9th " "	197.1	*0.3*
10th " "	197.9	*0.3*
	198.3	*0.7*

A TEST FOR PERMANENCE OF ADJUSTMENT

After several months' use of this apparatus by a beginning class in experimental psychology and for research purposes (during which time the apparatus was moved from room to room) it was again tested for accuracy. At various intervals it had been tested with the Wundt hammer, but no changes in adjustment were made. This final test was made with the Cattell gravity chronometer in the same manner as the earlier tests. The first ten readings taken were as follows:

201	198
200	200
200	199
200	199
198	200

Av. 199.5 A.D. *0.8*

CONCLUSION

This test of the Hipp chronoscope according to the method proposed by Dunlap seems to justify the following conclusions:

1. The method is more accurate than that with the spring adjustment and removes the necessity of accurately controlled current source, when the four conditions stated at the beginning of the paper have been fulfilled.

2. The equality of magnet cores which is one of the above conditions, may be tested by finding whether the balance of

the armature is disturbed after the current has passed through *both* sets of magnets for a considerable length of time.

3. Any change in time due to a variation in current strength will indicate a lack of proper adjustment, and the manner in which the time changes will indicate the nature of the adjustment required.

4. The Wundt hammer may be adapted by a change of wiring to serve as a fairly accurate control when the chronoscope is used in this manner.

5. No chronoscope which has given good records with springs, should be used for Dunlap's method until by proper adjustment it can withstand such a test as that outlined in this paper.

THE MÜLLER-LYER ILLUSION WITH CHILDREN AND ADULTS

BY RUDOLF PINTNER AND MARGARET M. ANDERSON

Ohio State University

The well-known illusion first described by Müller-Lyer was shown by the writers to children of different ages, varying from six up to fourteen. The original purpose of the work was to discover whether such an illusion could not be utilized as a suggestion test that might find its place among other mental tests. Work already done by Binet[1] and by Seashore and Williams[2] with this illusion showed some difference in the responses of children and adults. Rivers[3] found that children were more influenced by the illusion than men to the extent of 3 mm., with a standard of 75 mm., though the judgments of women varied very slightly from those of children. In the work of van Biervliet[4] the influence on children seems to be much greater since it is about twice as much as with adults, and they show about twice the mean variation. Winch[5] reports a greater degree of suggestibility to the vertical-horizontal illusion among children than among adults. None of these writers had tested large numbers of children at each age and, though all report a decrease in the amount of the illusion with an increase in age, their results scarcely show how this decrease of the illusion takes place from year to year. It was felt by the writers that if this

[1] Binet, A., 'La Mesure des Illusions Visuelles chez les Enfants,' *Revue Philosophique*, Vol. XL., 1895, p. 11.

[2] Seashore and Williams, 'An Illusion of Length,' *Psychological Review*, VII., 1900, p. 592, and 'Visual Perception of Interrupted Linear Distances,' Univ. of Iowa Studies in Psychology, Vol. II., 1899, p. 5.

[3] Rivers, W. H. R., 'Observations on the Senses of the Todas,' *British Journal of Psychology*, I., 1904–5, p. 321.

[4] Biervliet, J. J. van, 'Nouvelles Mesures des Illusions Visuelles chez les Adultes et les Enfants,' *Revue Philosophique*, Vol. 41, p. 169.

[5] Winch, W. H., 'The Vertical-Horizontal Illusion in School Children,' *British Journal of Psychology*, Vol. 2, p. 220.

decrease were marked and if the average deviation at each age were relatively small, some correlation between the amount of the illusion and general intelligence might be discovered, so that we might have a suggestion test, easy to apply and definite in interpretation. It might be said at the outset that these hopes of the writers were not realized as the results came to hand.

The Method of Procedure.—The apparatus employed followed the usual type used to measure this illusion. On a base-board two pieces of tin were fastened so that the one moved easily under the other which was stationary. The stationary piece had fastened on it a piece of paper with the line having the acute angles and the sliding piece had a similar paper with the line having the obtuse angles at the farther end. This is almost exactly the same as the apparatus used by Rivers.[1] The length of the stationary line was 12.7 cm., having acute angles of 35 degrees. The length of the movable line was 16.4 cm., with the oblique lines making angles of 146 degrees. The thickness of the lines was about 2.5 mm. On the reverse side of the base-board an aperture was cut large enough to allow a millimeter scale to be affixed by means of which the amount of the illusion could be readily determined.

Each observer was given six trials, three with the movable slide extended as far as possible and three with the slide pushed in as far as possible. In the one case the movable line was very obviously too long and in the other very obviously too short. The illusion board was given to the observer and he was told to push in the movable slide until the two lines looked equal. He was shown in each case how the apparatus worked. In the second three trials he was told to pull the slide out. The children were told to 'make the two lines look the same' or 'look equal.' None of the children were found to be familiar with the illusion. Among the adults those who were found to be familiar with it were told to make the two lines look the same and not to try to overcome the illusion by means of estimating how much

[1] *Op. cit.*

shorter the one ought to look in order to be equal to the other. In all, 250 children, varying in age from six to fourteen, and 28 adults acted as observers.

In regard to the behavior of the observers it was noted that, on the whole, the adults took a much longer time than the children to make their judgments. They showed greater care and deliberation. Many of the children came to a decision very rapidly. Among some of the younger ones, notably the six-year-olds, it is questionable whether they really understood what was required. This rapidity and flightiness of judgment shown by the children is reflected in the larger average deviation of the younger children, as will be noted below.

The Results.—The first set of three judgments made with the movable line extended, obviously longer than the standard line, has been called the First Series. The second set of three judgments where the comparison line is obviously shorter than the standard line has been called the Second Series. The difference between these two series is so great and so constant at all ages that it seems best to deal with them separately rather than with an average of the two series. The average amount of illusion of the three trials and the average deviation for each individual for each series was computed. These figures obviously cannot be given here. Since our main interest lies with the change in the amount of the illusion at each age, it will suffice to give the average amount of illusion at each age.

The amount of illusion in all cases, except where percentage of illusion is given, is measured in millimeters, showing the excess or positive amount added to the variable line by the observer. There are a few cases in which the observer made the variable line shorter than the standard. This error occurs very seldom and seems to be more common among younger children. Since it does not appear constantly in any three or six judgments of the individual, it is very probably due to inattention or lack of comprehension on the part of the observer. This error appeared very seldom among the adults.

TABLE I

FIRST SERIES

Age	No. of Observers	Averages of Judgments			Average of the Three Judgments	Average Deviation	General Average Deviation	Percentage of Illusion
		1st	2d	3d				
6	14	21.2	18.0	17.6	18.79	3.53	6.7	14.8
7	24	17.6	17.6	20.4	19.90	4.96	9.0	15.7
8	38	16.4	17.2	19.1	17.60	3.72	8.7	13.8
9	32	18.7	18.6	19.3	18.80	3.20	7.2	14.8
10	34	17.3	16.9	18.6	17.81	2.88	4.9	14.0
11	37	14.7	18.1	17.7	17.55	3.87	7.7	13.8
12	34	15.7	17.2	18.0	17.20	3.44	6.4	13.5
13	19	17.8	17.4	18.0	18.20	2.78	7.5	14.3
14	18	15.0	13.4	14.2	13.29	3.10	6.9	10.5
Adult	28	16.1	16.8	16.8	15.40	2.54	7.8	12.1
F. M.	13	20.6	16.1	17.9	18.15	4.55	4.5	14.3

Table I. shows the results for the First Series. The first column gives the age of the observer; the second the number of observers tested at each age; the next three columns give the average amount of illusion for the first, second, and third trials respectively; the sixth column shows the general average for each age of the individual averages for the three judgments; the seventh column shows the average of the average deviations of the three trials for each individual; the eighth column gives the general average deviation, *i. e.*, the deviations of the averages of the three trials for each individual from the general average for all the observers of the same age; and the last column gives the percentage of illusion calculated from the average of the three judgments. The percentage of illusion is on the whole less in these experiments than the percentages reported by Rivers[1] and by Seashore and Williams.[1]

Table II. gives the corresponding results for the Second Series, in which the comparison line was pulled out until it appeared equal to the standard.

Curves I., II., III., and IV. show the average amount of illusion at each age for each series for the first, second, third, and average judgments respectively. A glance at these curves shows that in general the illusion tends to decrease

[1] *Op. cit.*

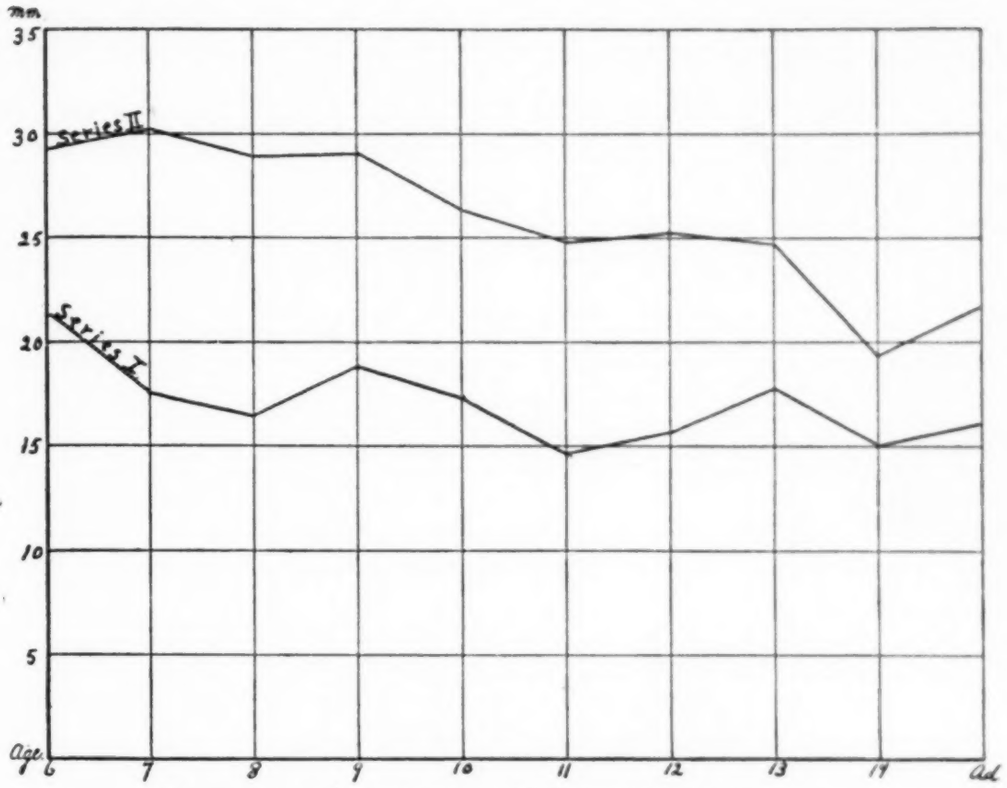
with increasing age. Some of the curves show a fairly uniform decrease, but every now and then there are drops and rises in the curves that spoil the general symmetry of the whole. The most noticeable is the drop at age fourteen on almost every curve. Why there should be this decrease in the amount of the illusion at fourteen does not seem explicable. There appeared to be nothing exceptional in the group of fourteen-year-olds to mark them off in any way from the other children or from the adults. It is true that the number of fourteen-year-olds was not quite as large as in most of the other ages, although we have as many at this age as at ages six and thirteen.

TABLE II

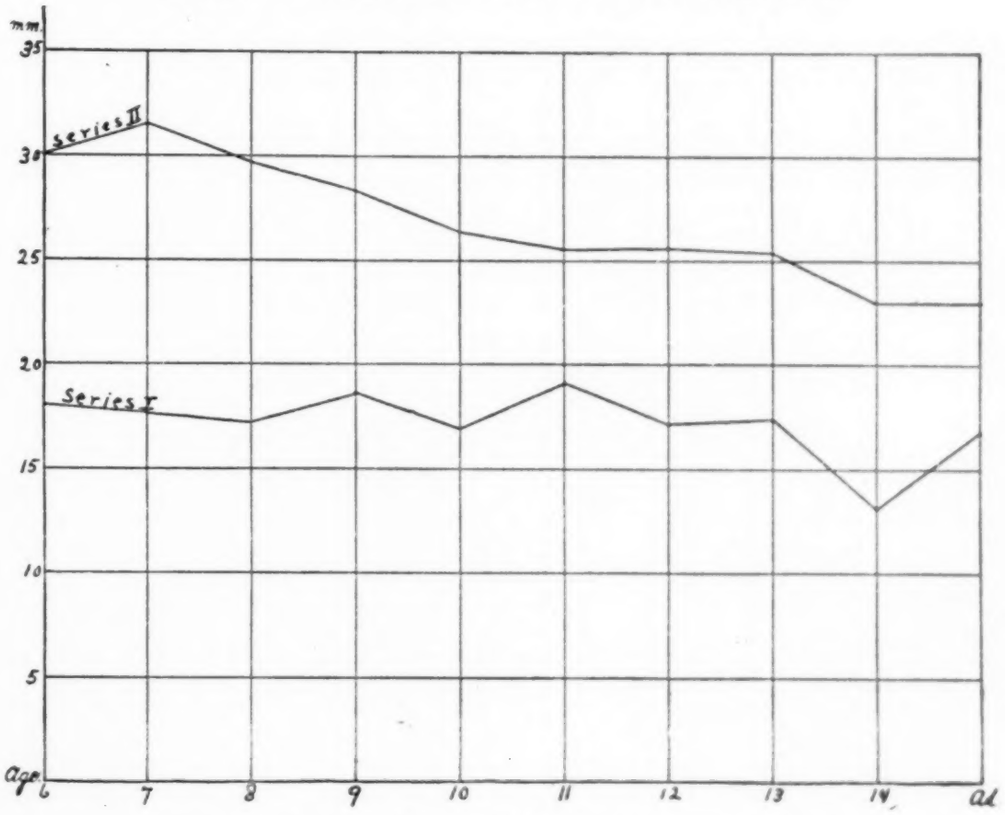
SECOND SERIES

Age	No. of Observers	Averages of Judgments			Average of the Three Judgments	Average Deviation	General Average Deviation	Percentage of Illusion
		1st	2d	3d				
6	14	29.3	30.0	34.4	31.07	3.71	7.3	24.5
7	24	30.2	31.5	32.0	32.70	3.24	7.1	25.7
8	38	28.9	29.7	29.2	30.40	3.48	8.5	23.9
9	32	29.0	28.4	28.8	28.56	3.02	7.4	22.5
10	34	26.4	26.4	27.0	26.80	1.92	5.3	21.1
11	37	24.9	25.6	24.9	25.45	2.79	7.4	20.0
12	34	25.2	25.6	25.2	24.88	2.51	5.9	19.6
13	18	24.8	25.4	26.3	25.50	2.16	5.5	20.1
14	18	19.4	23.0	23.7	22.50	2.30	5.5	17.7
Adult	28	21.9	23.0	22.6	22.40	1.54	6.8	17.6
F. M.	13	26.3	24.2	21.8	24.10	3.24	6.7	19.0

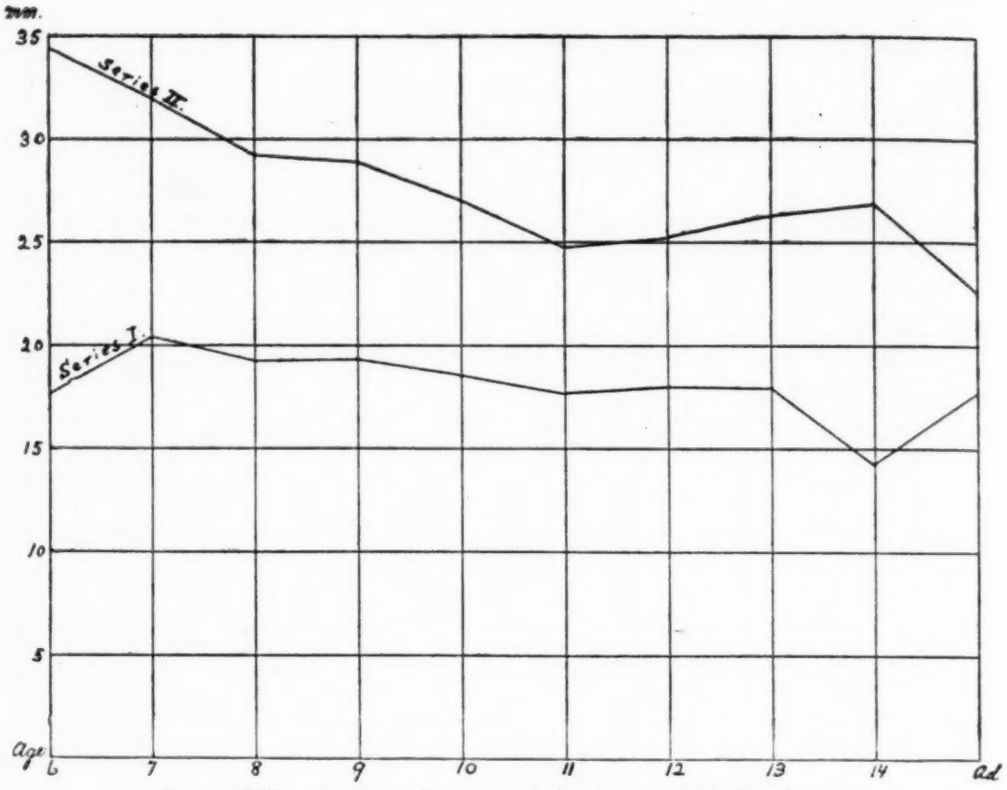
It is obvious from these curves that the difference between the amount of illusion at any two ages is never sufficient to mark off one age from another, so as to make this illusion useful as a test. And this is more obvious when we examine the figures in Tables I. and II. a little more carefully. The general averages for the three judgments fluctuate between 15 mm. and 20 mm. for the First Series (neglecting the drop to 13 mm. at age fourteen), and between 22 mm. and 32 mm. for the Second Series. In the First Series there is a difference of 5 mm. distributed over ten age groups and in the Second Series a range of 10 mm. distributed over ten age groups. In the last series this difference is indeed fairly well marked



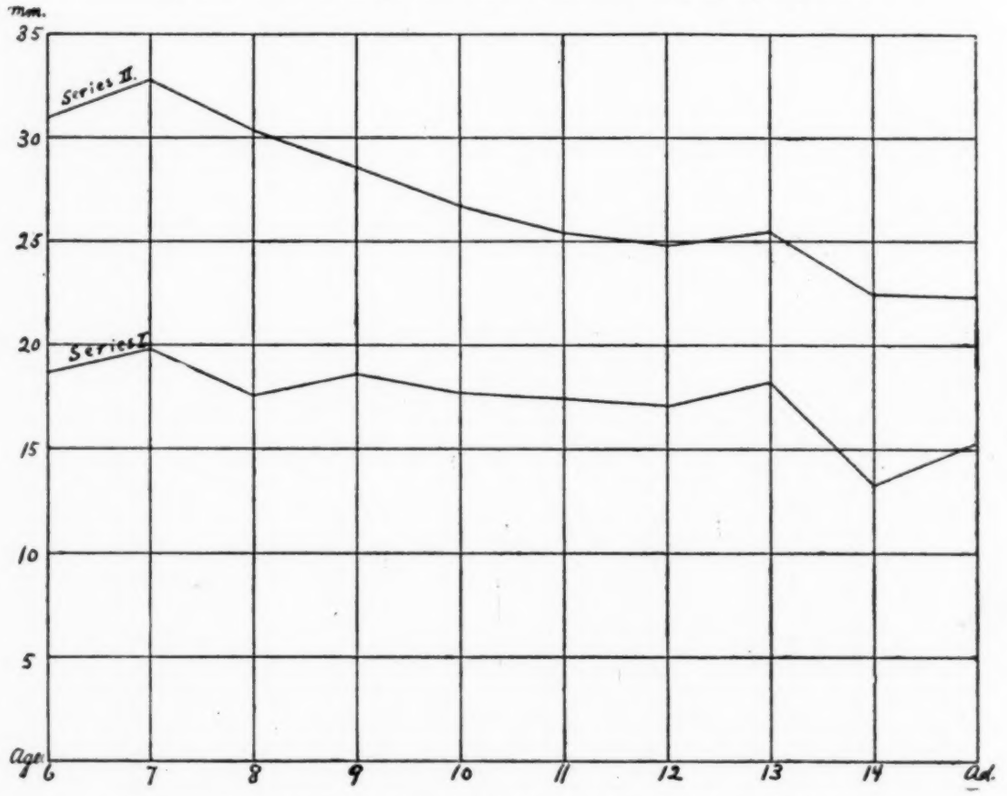
CURVE I. Average Amount of Illusion for First Judgment.



CURVE II. Average Amount of Illusion for Second Judgment.



CURVE III. Average Amount of Illusion for Third Judgment.



CURVE IV. Average Amount of Illusion for the Three Judgments.

and yet any hope of seeing a constant tendency in the amount of the illusion at any one age is marred by an inspection of the general average deviations in the eighth column. These large average deviations at almost every age show that there is little uniformity in the amount of the illusion to which an individual may be subject according to his age. There are many adults who are more subject to the illusion than many of the younger children. If we are to believe that this illusion decreases owing to the individual's increasing experience at estimating distance, it seems hard to understand these discrepancies although in a very general way this may be correct, since there undoubtedly is a constant tendency to decrease present. Again it would seem as if there is only a very slight increase in the uniformity of judgment in the individual as he grows older. The average fluctuation of the individual in his six judgments is shown in the seventh column under average deviation. On the whole it would seem that as the child grows older he becomes more uniform in his attitude, that is to say, he varies less from one judgment to the other. As we have noted above, the larger amount of the individual deviation in the lower ages corresponds well with the rapidity and flightiness of the child's behavior in making his judgments.

Both the tables and the curves show very markedly the great difference between the first and second series. This same difference appears in the results of Rivers.[1] Binet[1] calls this an error due to expectation, and in conformity with the more general phenomena of contrast. Binet's variable line, however, was the line enclosed by the acute angles and the method of presentation was radically different from ours.

It seems to us that the general tendency of the observer is to continue pulling out the slide until the comparison line looks almost longer than the standard. For most observers there is undoubtedly quite a considerable field within which the two lines are equal. Beginning with a much shorter line he does not stop when he first reaches the field, but tends to go on a little further to see if this is just right, and

[1] *Op. cit.*

indeed often until the comparison line looks slightly too long. This was seen from the behavior of many observers who pulled out the slide and then pushed it slightly back. The reverse conditions would hold for the First Series, beginning with the long line.

TABLE III

TABLE OF DIFFERENCES

Age	No. of Observers	Differences Between the Two Series			Difference of Averages
		1st	2d	3d	
6	14	8.1	12.0	16.8	12.28
7	24	12.6	13.9	11.6	12.80
8	38	12.5	12.6	10.1	12.80
9	32	10.3	9.8	10.5	9.76
10	34	9.1	9.5	8.4	8.99
11	37	10.2	7.5	7.2	7.90
12	34	9.5	8.4	7.2	7.68
13	19	7.0	8.0	8.3	7.30
14	18	4.4	9.9	9.5	9.21
Adult	28	5.8	6.2	5.8	7.00

The difference between the first and second series at each age is shown in Table III. In the columns headed first, second, and third judgments are shown the differences between the average judgment for the First and Second Series at each age. In the last column the differences between the averages of the two sets of judgments are given. These differences show the excess in millimeters of the Second Series over the First. It is interesting to note how uniformly this difference decreases from age to age. Undoubtedly the factors, whatever they may be, that are at work in making us pull out the standard line too far in the Second Series, are not nearly so effective as we grow older. Not only does the uniformity in judgment become greater in the three trials of each series but also in the two series compared with each other.

Thirteen feeble-minded individuals, all of whom had been rated about nine years mentally according to the Binet Scale, were also tested with this illusion. The results are shown in the tables on the line marked F. M. There is nothing very exceptional in the results. Their average judgment on the First Series corresponds to the judgments of the

children, since it is larger than the average judgment of the adults. This is true also of their judgments in the Second Series. The individual average deviation is large, particularly in the First Series, indicating a great fluctuation in individual judgments. If this is an indication of fluctuation in attention, it would be very appropriate with this group. The general average deviation is very much like the average deviations for normal individuals. It indicates, as in the normals, wide fluctuations between the individuals of the group.

Conclusions.—The Müller-Lyer illusion cannot be used as a test for suggestion which will correlate with general intelligence as measured by increase in chronological age. With increasing age there is a gradual decrease of illusion along with a gradual decrease in individual fluctuation. Neither of these decreases is uniform. At each age we have a large general average deviation, which indicates a great fluctuation between the individuals of each age group. We may deduce from this that the decrease in the illusion is due to the individual's increasing experience in judging distances as he grows older, but this can only be true in the most general sense. Or we may agree with Binet[1] when he says that the illusion is "innate" or "physiological," since the differences in the amount of the illusion between one age and any other age are not very great, and since the individuals in each group vary so much. Rivers[2] did not find Englishmen superior to savages (Todas and Murray Islanders) in this illusion, in spite of the fact that university students would have naturally had more experience in judging distances, especially in dealing with geometrical figures.

Considering the illusion 'innate' or 'physiological' and therefore more or less equally potent to all observers, the slightly greater amount of illusion with younger children might be explained as a matter of attention. They are not able to attend so well to the task; they are more careless and therefore make larger errors. This would be borne out by

[1] *Op. cit.*
[2] *Op. cit.*

the larger average deviations of individual judgments in the lower ages. In this case we would have to suppose that the savages tested by Rivers were equal to civilized individuals, as far as attention is concerned. The emphasis we have laid upon attention would correspond well to Smith's[1] suggestion of some slight correlation between accuracy of work and smallness of illusion. Furthermore he looks upon individual variability as an index of the general factor of attention, and as we have noted above, the individual variability was greater among children than adults. Very probably all three factors of contrast, experience, and attention are operative in producing the illusion and in increasing the extent of the illusion with children.

[1] Smith, W. G., 'A Study of Some Correlations of the Müller-Lyer Visual Illusion and Allied Phenomena,' *British Journal of Psychology*, Vol. 2, p. 16.

REPORT OF PSYCHOLOGICAL TESTS AT REED COLLEGE

BY ELEANOR ROWLAND AND GLADYS LOWDEN

Reed College

It was the purpose of those conducting this investigation to discover if there were some practical and valuable grouping of psychological tests for college students which would give an index of relative mental ability. Our problem was to find if any group of tests showed correlation with the office grades in college subjects, granting the assumption that grades in college subjects are an indication of the mental ability of the student. The tests were carried out individually on all the students in Reed College, over a space of three years. Three classes received the tests during the sophomore year, and one during the freshman year.

A group of experiments was selected for trial which were standard tests for measuring the processes of memory, association, attention, suggestion, imagination and judgment. Both rote memory and logical memory were tested. For the former a series of 42 cards was used for auditory-visual-articulatory presentation, and the experiment was performed and evaluated according to Whipple's 'Manual of Mental and Physical Tests,' pp. 364–66. The logical memory test consisted of the reading twice to the subject of a story of ten logically related incidents, after which he was to write this story in the form in which it was read. As it contained 166 words, it is evident that it could be remembered only by meaning, that is by the dependence of one point on the preceding.

Complete success in the logical memory meant 10 points. Failure in one complete section of the ten meant a deduction of 1. Failure in one half a section meant a deduction of 0.5. Attention was measured by three different tests. For studying the range of visual attention, cardboards were prepared

each containing 10 unrelated objects. Each card was exposed six seconds, after which the subject was to repeat as many objects as could be remembered. In order to measure the degree of attention, cancellation blanks were used: first, where a single letter (a) was cancelled; second, four letters, (q, r, s, t); third, words containing both *a* and *t*. The test of crossing out assigned letter or letters or words from printed sheets demands maximal attention inasmuch as any reduction of attention is reflected at once in the speed or accuracy of the work done. A similar test eliminating the motor factor was given in asking the subject to count the number of o's in three paragraphs of prose without pointing. There were 53 o's in the paragraph.

The result for attention span was the average number of objects recalled from the seven exposures.

The three cancellation tests and counting o's were figured according to Whipple's 'Manual,' p. 261, on the basis of speed divided by accuracy where accuracy equals number cancelled over number present.

Uncontrolled association was tested in the usual way by giving the subject a test word after which he was to write as rapidly as possible sixty-six words suggested. The standard whole-part, species-genus, and opposite lists comprised the material for measuring controlled association. Simple addition, subtraction and multiplication were introduced to test even more strictly controlled association.

Uncontrolled association and controlled association by whole-parts, species-genus and opposites was scored on the basis of speed only. Hence shortest time indicates greatest success. In case of opposites, the final figure was the average time for three lists. Speed was divided by accuracy to give the figure for computation tests, exactly as in the cancellation tests.

Imagination was tested by creative ability in linguistic invention. Both Miss Sharp's method[1] of incorporating into sentences three nouns and verbs, and also Binet's method of partially written sentences to be completed were tried.[2]

[1] *A. J. P.*, 10, 1899, 329–391.

[2] Whipple's 'Manual,' p. 438.

For the linguistic invention, two sets of nouns and two of verbs were given. The final score was the average number of sentences for nouns and the average for verbs. Care was taken to strike out such sentences as repeated the thought with a change of tense or number. Sentence completion was recorded on the basis of speed. Hence shortest time was the greatest success.

In the first arrangement of tests were included but two of suggestion: progressive lines as first used by Binet, and suggestion by the illusion of heat, according to Whipple, p. 424.

The procedure for computing results in the line length test was according to Binet, 'La Suggestibilite,' p. 102.

Ten trials were given in the heat test, five with each hand, and record was made of the number of times heat was felt. Hence 0 was success; 10 failure.

Ten syllogisms, some true, some false, were used to test judgment. We also included a quick judgment test devised by Munsterberg, and described in 'Psychology and Industrial Efficiency,' p. 87.

In the winter of 1912–13 this grouping of psychology tests was tried out on 54 students of Reed College, none of whom had had experimental psychology, thereby eliminating the practice element. Each student was tested separately, and with careful planning on the part of the experimenter, the set could be completed within two hours.

When the scoring of each individual test was completed relative lists of the standing of each subject in each test were made in which the upper one half were considered high and lower one half low. For the purposes of correlation, credits in college courses earned by each student for the semester in which the tests were taken were secured from the college office, and arranged in a relative list in which the upper one half were considered high and the lower one half low. With the material in this form it was possible to work out the coefficient of correlation figures by substitution in the formula of Mr. G. Udney Yule.[1] The coefficient of corre-

[1] Jr. Royal Statistical Soc., Vol. LXXV., Part VI., pp. 579–642.

lation is called ω, and with the use of the four-fold table

a	b
c	d

ω is equal to $(1 - \sqrt{K})/(1 + \sqrt{K})$ where $K = bc/ad$. The error of this coefficient is equal to

$$\frac{1 - \omega^2}{4}\sqrt{\frac{1}{a} + \frac{1}{b} + \frac{1}{c} + \frac{1}{d}}.$$

Of course, the smaller the number of cases the greater the probability of error and for a coefficient figure to be really significant according to this formula it must be two or more times as great as the coefficient of error.

With but 54 cases it was to be expected that the percentage of error would be high, but after correlating each individual test with the credits for the semester and the tests as a whole with the credits for the semester, the results were sufficiently gratifying to warrant further investigation.

Some changes, however, were made in the grouping of the tests as a result of the first year's investigation. Uncontrolled association was omitted as taking too much time, and likewise for the reason that it seemed to be measuring the speed of handwriting rather than rapidity of association. It was felt likewise that the value of a free association test lies in its use as an indication of the type of association rather than its speed alone. Computation was omitted also because it seemed to take a disproportionate amount of time. Sentence completion was not repeated because of the low correlation and because of the impossibility of giving credit for the quality of sentences written as well as for the time required to complete them. Five tests were added. A new cause-effect association test, in which 24 sets of paired words connected by cause and effect were read at the beginning of the tests. At the completion of the tests, the first word for each pair was read and a record made of the number of second words, correctly recalled. The greater the number of correct associations the greater the success.

The attention tests showed good correlation: hence a dot-counting test devised by Binet and described in Whipple's 'Manual,' p. 270, wherein efficiency was equal to the average speed divided by the average accuracy was added.

Progressive weights after Binet[1] and comparison blocks after Gilbert[2] were added to the two suggestion tests.

To test mechanical ability the Healey puzzle box was introduced. The shortest time required for opening it constituted the greatest success.

With these revisions the group has been given to 195 more subjects, so that the results for 249 cases were available. On the basis of related lists for the 249 cases, correlation figures were worked out between grades in each mental test and credits in college courses for the semester in which the tests were taken with the result that the q, r, s, t cancellation test received the highest correlation $.18 \pm .06$.

Next to the q, r, s, t test, the association test by opposites received the highest correlation $.16 \pm .06$. At the first glance it seemed mere chance that determined the greater correlation of the lists of opposites, but closer analysis revealed a probable reason for this. It will be remembered that there were three lists of opposites and on each list there were twice as many words as on the whole-part, and the genus-species lists. Hence the chance for error was reduced by the wider range of the test.

Both logical memory and the judgment test (syllogisms) received a correlation of .13 with a percentage of error of .06.

In fact it was noticeable that the highest correlations between individual tests and college credits were for a difficult attention test, the most comprehensive association test, and the two tests requiring logical thought. No other correlations were significant. However, after all, we had no expectation of finding one single test of some one process which could be used as an indication of mental capacity. We hoped rather for a group of tests which would measure mental capacity in the one respect of correlating with office

[1] Whipple's 'Manual,' p. 410.

[2] *Ibid.*, p. 405.

grades. Hence the next step was an attempt to establish a correlation between some group of tests and the credits. Inasmuch as the q, r, s, t, opposites, logical memory, and judgment (syllogism) tests individually showed the highest correlation, it was most natural to group these four tests and correlate with grades. The resulting figure was .31 with a probable error of .06, showing an increase of .13 for the group correlation over the highest correlation figure for any individual test. Several other combinations of tests were tried, but the one combination raising the figure still higher was formed by adding to the four highest tests, the rote memory, and the attention by cancellation of words with a and t which resulted in a coefficient of correlation of $.37 \pm .06$.

During the process of correlating tests with credits as a whole, it was suggested that some interesting results might be reached by correlating tests with high grade of work in individual courses.

Mathematics and English were selected for the purpose, inasmuch as a larger number of students were enrolled in these courses, thereby reducing the percentage of error for correlations depending on these credits. The significant correlation between tests and credits in Mathematics was for the q, r, s, t, opposites, logical memory, and judgment group, $= .25 \pm .10$. However, it is to be noted that the percentage of error is higher owing to the fact that of the 249 who had taken tests, credits in mathematics were available for but 86.

More material was available for English courses, there being 211 cases. Different combinations showed the highest correlation for English to be between English and association by opposites, $= .26 \pm .06$.

We also worked out some correlations on the basis of sex. The results were as follows: a correlation of .20 between the men and superiority in the syllogism test, and .24 in resistance to suggestion in the line-length test. There was a correlation of .25 between women and superiority in cancellation of a, .38 in cancellation of q, r, s, t and .30 in counting o: that is in the principal attention control tests. The error was .06 in all.

It has been suggested that in a two-hour group of tests, fatigue may tend to render unreliable the results. No doubt this is true in individual cases, but in a group study of so many cases the factor of fatigue becomes unimportant. In an investigation of this kind it is always desirable to have but one experimenter, but owing to the number of cases and the length of time, twelve students of experimental psychology assisted in conducting the tests.

One might also question the assumed value of college grades, but at the present time, they are the standard measurement of ability of students in college classes.

However, in spite of difficulties, the correlation figures are sufficiently high to indicate the desirability of conducting further investigations in the line of mental tests for normal adults.

There seems to be little doubt that the revised list of tests did make a selection of the better students in Reed College. With information from this, and with further revisions, it is hoped to increase the value of this list and to interpret the results with regard to information about the individual student, rather than about the group alone. The latter is all that has been possible so far.

THE INFLUENCE OF THE EMOTIONS ON RESPIRATION

BY ANTOINETTE FELEKY

Columbia University

The experimental investigation here reported concerned itself with the respiratory changes which accompany the six primary emotions, pleasure, pain, anger, disgust, wonder, fear, as well as laughter and hatred. The respiratory changes studied are (1) duration of inspiration as compared with that of expiration, (2) changes in the depth or amplitude, (3) and changes in the amount of work accomplished per unit of time.

Introduction

This work grew out of a series of experiments begun in September, 1911, and continued until January, 1915, with a view of recording the influence of thoughts and feelings on the facial organs, known as "the muscles of expression." Over one thousand photographs of one individual, A. F., were taken for this purpose and studied. Samples of these were published in a previous article.[1] Although the camera recorded a great many interesting and valuable facts, many of which were interpreted with considerable success by the 100 judges, thus verifying the mental states revived by A. F. and recorded by the camera, we felt a need of supplementing this knowledge by recording other expressive movements. In order to get good results, we made our task as simple as possible, and concentrated all our efforts in recording and interpreting the respiratory movements only. For this purpose, and as a preliminary study, we had A. F. revive the various thoughts and feelings while the breathing movements were recorded.

The stimuli were the same as those used in posing before the camera: reciting poetry and prose; multiplying and other

[1] *Psy. Review*, Jan., 1914.

mental activities; reviving bodily movements of the emotions; sense stimuli, taste (sour, sweet, bitter), smell, sight, hearing (noise and harmony); feelings of strain, relaxation, fatigue, as well as the various sensations of pain (head, back, crushed fingers, toes, etc.).

We also studied the respiratory changes which accompany the various movements of the head, arms, upper portions of the body. In fact every conceivable movement was studied and recorded—chewing, swallowing, sneezing, coughing, yawning, sighing, sobbing, crying, speaking, singing and even dancing.

Many of the breathing records were genuine and spontaneous. For instance, while working one may naturally yawn or sigh from fatigue, swallow saliva, sneeze, cough, and make other movements such as 'stop to think,' 'stop to look,' which leave their stamp on the revolving drum of the smoked kymograph. The records of the spontaneous and genuine movements do not differ from the records of the assumed or revived movements. This fact is of great importance, for it seems to prove that the revived feelings express themselves as clearly in the respiratory muscles as they do in the facial muscles. This fact is also of great importance for us, as our experiment greatly depends upon the revived or imaginary stimuli. The reviving of habits of feelings and emotions need be no stranger than reviving the habits of walking, talking, writing, adding, multiplying. It is to be remembered that the newborn infant's experiences are first those of feelings of comfort and discomfort, of crying, sneezing, coughing, smiling, etc. In fact, almost all the primary emotions are experienced long before he attempts to walk.

After having obtained over 100 records of A. F., we experimented with four other subjects, graduate students in psychology (two men and two women), also as a preliminary study, in order to evolve a working method for our experiment. For a better understanding of the breathing curves, we recorded simultaneously the respiratory and facial movements (in the case of A. F. only).

From the results obtained, we concluded: First, that the

respiratory muscles speak as clear a language as do the muscles of the larynx (voice), or 'the muscles of expression' (facial organs), but that the three supplement each other, and each must be interpreted. For example, in laughing, crying, yawning, wonder and disgust, the accompanying facial expressions are characteristic; the respiratory movements are modified, and record differently in each case; the vocal cords are thrown into characteristic vibrations. Second, that the feelings and emotions are principally reflected in the 'muscles of expression' and that of respiration. Third, that the emotions are intense feelings, and may be accounted for by the summation of stimuli.

The above suggestions and conclusions are not new. The physiological and psychological investigations on our subject need not be discussed here. However, we may draw attention to the following important facts: Charles Bell, the discoverer of Bell's law, Bell's palsy (facial paralysis), points out the fact that the act of respiration is not limited to the trunk, but includes also the nose, mouth, the windpipe, the throat, the lips, so that the air may be admitted through them in respiration with a freedom corresponding with the increased action of the chest. He proves that the organ of breathing, in its association with the heart, is the instrument of expression, and is the part of the frame by the action of which the emotions are developed and made visible to us. Sudden changes of color in the countenance denote disturbances in the heart's action; labored, irregular breathing of the chest, extending to the neck and face, mark corresponding interruptions to the action of the respiratory organ; and both give rise to the variety of expression, which man interprets as a natural language. Bell not only shows the natural association between the muscles of the face and that of respiration, but he also gives experimental and clinical evidence to prove that in facial paralysis, the muscles of the

[1] "When a horse has run and pants and breathes hard, the nostrils are alternately dilated and contracted, while the chest rises and falls. So in man, excited by exercise or passion, the shoulders are raised at each inspiration, the muscles of the neck and throat are violently drawn, and the lips and nostrils move in time with the general action." ('The Anatomy of Expression,' by Chas. Bell, p. 7, second ed. also eighth ed.)

face are powerless, and the countenance acquires a characteristic look from the absence of all expression.

Darwin[1] points out that one of the most important facts brought out by Bell is that the muscles round the eyes are involuntarily contracted during violent respiratory effort, and that this fact aids to throw a great deal of light on many of the important expressions in man.

More recent investigations, including those of Mosso, Sherrington, Crile, and Cannon, seem but to strengthen and uphold Bell's conclusions, which are also in accord with our own views. For our purpose, we may merely state that Mosso[2] gives evidence and concludes that "the emotions are principally reflected in the muscles of the face and that of respiration." Bell[3] as well as Mosso draw attention to the fact that the human countenance performs many functions: we find "the organs of mastication, of breathing, of natural voice and speech, and of expression. The face serves for the lowest animal enjoyment, and reflects the highest and most refined emotions."

Cannon[4] states that the differential features of emotions are not to be traced to the viscera, and that this view is also in accord with the experimental results of Sherrington.

Crile[5] states with Sherrington that "the environment drives the brain, the brain drives the various organs of the body." He adds that each separate motor action has its own brain pattern, which is adapted for but one type of motion, and that "the specific stimuli of the innumerable ceptors play each upon its own brain pattern only. In addition each brain pattern can react to stimuli applied only within certain limits."

In regard to the psychological investigations, we must be brief. Both Stevens[6] and Shepard[7] publish experiments on organic changes and feeling and attention, and both review

[1] 'Expression of the Emotions in Man and Animals,' Chas. Darwin, p. 2, 1873.
[2] 'Fear,' Angelo Mosso, p. 164, 1896.
[3] *Op. cit.*, p. 5 and 6.
[4] 'Bodily Changes in Pain, Hunger, Fear, and Rage,' Cannon, p. 280, 1915.
[5] 'The Origin and Nature of the Emotions,' S. W. Crile, p. 90, 1915.
[6] 'Study of Attention,' H. C. Stevens, *Am. Jour. of Psy.*, 1905.
[7] 'Organic Changes and Feeling,' J. F. Shepard, *Am. Jour. of Psy.*, 1906.

the writings on this subject. Stevens concludes that the psychophysical processes of sensation are different with the visual, auditory, and tactual. Shepard[1] studied Stevens's records and states that as far as any conclusion can be drawn from them, the differences are due to changes in breathing.

Our own observations seem to show that we may not only have visual, auditory, and tactual attention, but we may also have pleasant, fearful, angry, etc., attention, and when the intensity of the feeling is increased, we experience the various emotions. We may say with Wundt[2] that intense feelings are emotions. "As a result of the summation and alternation of successive stimuli there is in emotion not only an intensification of the effect of the heart, blood-vessels, and respiration, but the external muscles are always affected in an unmistakable manner. Strong movements of the mimetic muscles appear at first, then movements of the arms and of the whole body (pantomimetic movements). In case of stronger emotions there may be still more extensive disturbances. . . ."

As each emotion has a characteristic expression, we may expect to find corresponding changes in the respiratory apparatus. This is the object of the following experiment.

Apparatus and Method

Records were taken of the respiratory movements by means of Ellis's pneumograph, a closed tube distended by a spiral spring and fastened around the chest of the subject. Inspiration changes the air pressure in the tube, and this change is transmitted to a Marey tambour which writes the respiratory movements on the smoked surface attached to a drum of Porter's kymograph. Time in seconds was recorded by means of a Jacquet chronometer.

In order to simplify measurements, Benussi's[3] method of tracing each record on unit paper was employed. As milli-

[1] 'The Change of Heart Rate with Attention,' Billings and Shepard, *Psy. Review*, 1910.

[2] 'Outlines of Psy.,' 3d ed., 1907, W. Wundt.

[3] *Archiv. Gesamte Psy.*, Jan., 1914, p. 244. Article "Die Atmungs symptome der Lüge," by V. Bennussi.

meter paper was not available, the unit paper, having 1/20th of an inch to a unit, was used. The beginning and ending of each inspiration and expiration was projected on that straight line which conformed to the horizontal position of the writing pen.

There were six subjects: A. F., who had training in posing for the various graded emotions with or without the camera, and five other women who had no such training. Among the latter were three actresses, one singer and one school teacher.

The subjects were seated in a comfortable position beside a table upon which stood the registering instruments. In order not to distract the attention of the subject, the instruments were hidden from view by a screen.

The questions asked and instructions given to the subjects were as follows: "Have you ever found yourself smiling or laughing at some experience which had previously made you smile or laugh?" This question was answered affirmatively by all. "Now recall an experience which gave you pleasure and try gradually to increase this pleasure to your utmost capacity, then suddenly think of something funny and pleasurable, and begin to laugh." A similar question was asked in regard to the emotion of anger. The subject was then told to revive the emotion and gradually to increase the intensity and finally to say the words, 'I hate you,' at the same time to try as much as possible to feel this hatred. The same directions were given in the case of the emotions of pain, disgust, wonder and fear. The last four were merely increased in intensity without a change from pleasure to laughter, or from anger to hatred. Thus the revival of the six emotions, pleasure, pain, anger, wonder, fear, and disgust, which the writer considers the primary emotions, were employed.[1]

[1] The seven primary emotions named by McDougall include fear, disgust, wonder and anger. He adds the emotions of subjection, elation and the tender emotion, and states that "from these seven primary emotions together with feelings of pleasure and pain (and perhaps also feelings of excitement and of depression) are compounded all, or almost all, the affective states that are popularly recognized as emotions." As our objectivized emotions (photographs) seem to show some overlapping in this classification, we therefore substituted pleasure and pain, which have characteristic expressive movements, for elation, subjection and the tender emotion. In fact the

In order to make the situation as natural as possible, we had A. F., the trained subject, assume the various emotions together with the other subjects.[1] This helped to do away with some self-consciousness, which was very noticeable. This was more apparent in the school-teacher, who had no musical or dramatic training, than in the singer and the actresses, although all seemed self-conscious until A. F. worked with them. Attention must be drawn to the fact that the intensifying of the emotions in this manner is arbitrary, and not the natural mode of expressing them. Each situation will bring along with it a certain degree of emotion, but in order to study the various intensities of the different emotions pure and simple this seemed the most practicable way.

The first record was simply taken to orient the subject to his task. Enlarged photographs of A. F. of the various degrees of pleasure culminating in laughter were shown to the five subjects. A normal curve was taken for some seconds, then one photograph was shown at a time. The subjects all smiled when shown the smiling expression and increased their smiling, corresponding to the intensity found in the photos. The breathing records also showed corresponding changes. Then the different emotions were revived.

It was to be expected that the effect upon the respiratory organs, produced by varying the intensity of the different emotions, would not turn out as perfectly as desired. Then again, the various emotions are inhibited more by some individuals than by others.

One subject mentioned that she seldom is provoked to anger and seldom hates. The only person this subject ever hated was an uncle who defrauded her of an inheritance. Two other subjects were under the impression that laughing aloud is not proper, therefore they always suppressed it, or

parental instinct not only excites the tender emotions, but also all the emotions which we consider are the primary emotions.

[1] It is well known that just as a frightened animal may communicate fear to another animal, so may one individual spread joy or fear to another. Thus our stimuli consisted not only in the revived emotional experiences of the subject, but also the bodily expressions of the emotions in another individual.

laughed inwardly. Thus taking into consideration the difficulties encountered, and for the sake of uniformity, we have eliminated in our measurement all the curves with the exception of the five middle ones, which would give us only the medium degree of each emotion. In the case of wonder, where the curves are characteristic, one respiratory phase, which includes an inspiration and an expiration, was all that was necessary for measurement. The downward stroke corresponds to inspiration and the upward stroke to expiration.

The following figures show the character of respiration during normal breathing, and the medium degree of the emotions of pleasure, pain, anger, disgust, wonder, fear, laughter and hatred. The amount of respiratory work accomplished per unit of time was found by dividing the amplitude, which is both force and distance, by the time taken for each respiratory phase. Thus the sum of the five middle amplitudes or inspirations was taken and divided by the time taken by five inspirations and five expirations. In the case of wonder only one amplitude was measured.

Column I. gives the results for the relation between inspiration and expiration. When I. : E. as 3 : 3, or 4 : 4, or 5 : 5, etc., we get a ratio 1.–. When the ratio is less than 1.– the time for inspiration is less than the time for expiration. When the ratio is greater than 1.– then the time for inspiration is greater than that of expiration. The inspiratory pause was included as a part of inspiration, as may be seen in the characteristic curve of 'wonder'; and the expiratory pause was considered as belonging to expiration, as shown in the breathing curves of laughter and hatred. Only the beginning of each inspiration and expiration was marked off for measurement. That is the end of the first inspiration including what is considered a pause (if one exists) was of course the beginning of the expiration; and the end of the expiration was the beginning of inspiration.

We may summarize in Table II. and Table III. the average results and the mean variations of the respiratory changes, and the rate of work per second during normal breathing and the medium degree of the six primary emotions. Laughter and hatred are tabulated separately (Table III.).

TABLE I

1. NORMAL

	I./E.	Depth	Work per Sec. in Units Where 1 Unit Equals 1/20 of an Inch
Subject A. F.	.74	12.7	5.18
" F. M.	.81	14.24	4.73
" M. M.	.83	14.2	4.08
" D. L. E.	.79	11.7	4.09
" L. B.	.75	15.	5.76
" I. M.	.91	15.5	4.20
Average	.805	13.89	4.67

2. DURING DISGUST

	I./E.	Depth	Work per Sec.
Subject A. F.	.85	7.9	4.44
" F. M.	1.24	6.7	4.21
" M. M.	.66	17.	5.70
" D. L. E.	1.07	21.9	5.01
" L. B.	.75	24.2	9.75
" I. M.	1.93	14.2	6.48
Average	1.08	15.31	5.93

3. DURING WONDER

	I./E.	Depth	Work per Sec.
Subject A. F.	3.5	47.	7.66
" F. M.	2.45	40.5	6.15
" M. M.	3.	34.	6.85
" D. L. E.	2.25	33.	4.19
" L. B.	1.64	45.	8.68
" I. M.	2.14	32.	4.79
Average	2.49	38.58	6.39

4. DURING PAIN

	I./E.	Depth	Work per Sec.
Subject A. F.	2.	26.5	8.16
" F. M.	1.7	22.4	3.74
" M. M.	1.12	29.5	5.70
" D. L. E.	1.71	37.7	6.92
" L. B.	.78	27.8	14.62
" I. M.	1.97	34.	9.03
Average	1.546	29.65	8.028

5. During Pleasure

	I./E.	Depth	Work per Sec.
Subject A. F.	1.05	24.	9.42
" F. M.	1.33	30.1	9.85
" M. M.	1.10	24.1	6.15
" D. L. E.	1.26	34.2	7.56
" L. B.	1.20	21.8	12.33
" I. M.	.73	29.4	11.47
Average	1.11	27.26	9.465

6. During Anger

	I./E.	Depth	Work per Sec.
Subject A. F.	1.87	36.2	17.32
" F. M.	1.36	25.5	10.82
" M. M.	.84	32.3	16.69
" D. L. E.	1.72	38.1	15.13
" L. B.	.52	18.1	9.41
" I. M.	2.57	40.5	10.43
Average	1.48	31.78	13.30

7. During Fear

	I./E.	Depth	Work per Sec.
Subject A. F.	3.31	22.3	15.68
" F. M.	2.19	17.15	10.14
" M. M.	2.55	41.8	23.20
" D. L. E.	3.93	25.5	10.58
" L. B.	1.59	52.	13.70
" I. M.	2.39	39.8	14.12
Average	2.66	33.19	14.57

8. During Laughter

	I./E.	Depth	Work per Sec.
Subject A. F.	.22	34.	11.58
" F. M.	.39	22.6	7.31
" M. M.	.34	21.65	11.66
" D. L. E.	.22	30.6	9.
" L. B.	.36	20.	4.47
" I. M.	.27	30.5	6.47
Average	.30	26.55	8.415

9. During Hatred

	I./E.	Depth	Work per Sec.
Subject A. F.	.275	35.	4.67
" F. M.	.745	45.25	9.28
" M. M.	.99	30.08	16.25
" D. L. E.	.45	37.8	9.6
" L. B.	.49	10.4	.88
" I. M.	.14	12.	4.095
Average	.515	28.42	7.462

TABLE II

	I./E. (in Units)	Depth (in Units)	Rate of Work per Sec. (1 Unit = 1/20 of an Inch)
NORMAL			
av.	.805	13.89	4.67
m.v.	.045	2.	.55
DISGUST			
av.	1.08	15.31	5.93
m.v.	.33	5.71	1.45
WONDER			
av.	2.49	38.58	6.39
m.v.	.50	5.58	1.34
PAIN			
av.	1.546	29.65	8.028
m.v.	.398	4.14	2.57
PLEASURE			
av.	1.11	27.26	9.465
m.v.	.15	3.96	1.75
ANGER			
av.	1.48	31.78	13.30
m.v.	.57	6.65	3.08
FEAR			
av.	2.66	33.19	14.57
m.v.	.64	11.44	3.24

TABLE III

	I./E. (in Units)	Depth (in Units)	Rate of Work per Sec. (1 Unit = 1/20 of an Inch)
LAUGHTER			
av.	.30	26.55	8.415
m.v.	.06	5.14	2.33
HATE			
av.	.515	28.42	7.462
m.v.	.24	11.48	4.25

The above record gives I. : E. : : 4 : 5(.805) during normal breathing. This shows rather clear results when we consider that the mean variation is .045; and that the ratios obtained by various investigators vary from 2 : 3, 3 : 4, 4 : 5, or 6 : 7. (That is the time for inspiration is less than the time for expiration.) The average depth during normal breathing is 13.89 (m.v. 2.–); and the rate of work per second is 4.67 units (m.v. .55). Fig. 1 gives A. F.'s and L. B.'s breathing curve during normal respiration. In the latter, the first five curves were measured; in the former, the last five curves.

In disgust the average ratio is 1.08 (m.v. .33). Subjects A. F., M. M., L. B. give less time for inspiration than expira-

tion, while the other three subjects give more time for inspiration than for expiration. The average depth is 15.31 (m.v. 5.71). In order to explain this irregularity, we will introduce

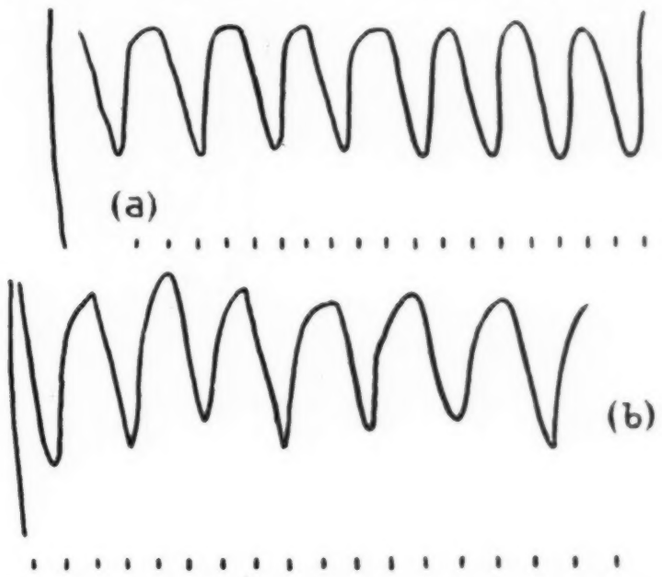


FIG. 1. (*a*) Subj. A. F.—I. : E. = .74 units; depth, 12.7;[1] rate of work per sec. 5.18 units. (*b*) Subj. L. B.—I. : E. = .75 units; depth, 15.–; rate of work per sec. 5.76 units.

the breathing curves as shown in Fig. 2. It seems as though the subjects A. F. and F. M. inhibit their breathing to a much greater extent than the others. The nose is very largely a respiratory organ; and in disgust is often slightly contracted as partly to close the passage (Bell; Darwin). Then again the terms which express immediate personal attraction or repulsion are derived for the most part from the sense of smell and taste. To loathe is much the same as to be nauseated at something. Disgust is a strong term for personal repugnance, and even in its objective manifestation centers about the curl of the nostrils and of the mouth.[2] Then there

[1] We can in calculations convert 12.7 units (depth) into amount of air breathed in, which, in the case of A. F. is 216.44 c.c. These figures were obtained by breathing into a standard water spirometer at various levels, not exceeding 40 c.i., while a pneumograph was strapped around the chest, and a record was obtained upon a smoked surface of a drum. These records were then measured by means of the unit paper. We thus calculated that one unit equals 1.04 c.i. or 17.9425 c.c. This is the average of 96 trials with levels ranging from 10 to 40 c.i. A. F.'s vital capacity was found to be 143 c.i. or 2,343.34 c.c.

[2] 'Psy.,' Dewey, p. 257.

are various ways of exhibiting disgust, as shown by Darwin.[1] If the guttural sound 'ugh' is employed, as in the case of A. F. and F. M., the breathing is inhibited, and thus the

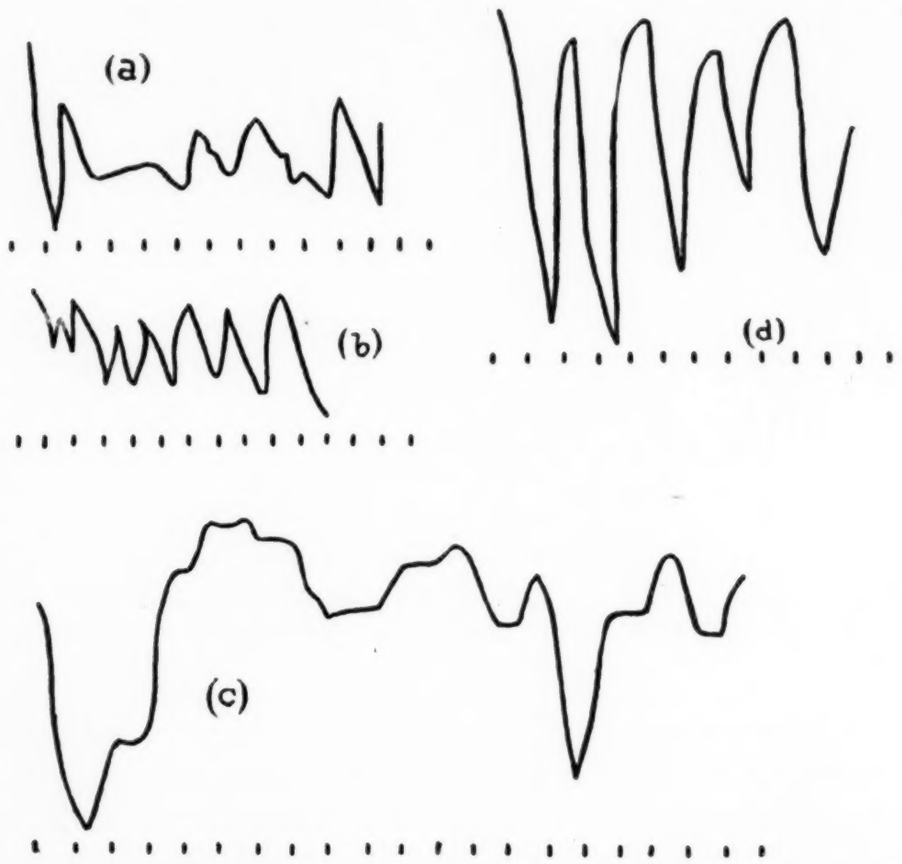


FIG. 2. (*a*) Subj. A. F.—I. : E. = −.85 units; depth, 7.9; rate of work per sec. 4.44 units. (*b*) Subj. F. M.—I. : E. = 1.24 units; depth, 6.7; rate of work per sec. 4.21 units. (*c*) Subj. M. M.—I. : E. = .66 units; depth, 17.–; rate of work per sec. 5.70 units. (*d*) Subj. L. B.—I. : E. = .75 units; depth, 24.2; rate of work per sec. 9.75 units.

rate of work. M. M. gives first a deep inspiration followed by a long irregular expiration and then inhibited respiration. A breathing curve similar to this, but a little more regular is given in Plate II.; and seems to be a typical curve for the 'emotion of disgust.' That is, there is first a quick deep inspiration and then expiration followed by inhibited respiration.

Fig. 3 gives the characteristic breathing curve of 'wonder' with its decided inspiratory pause. The average ratio for the six subjects is 2.40 (inspiratory pause is included as

[1] 'The Expression of the Emotions in Man and Animals,' C. Darwin, p. 258.

belonging to inspiration), with a m.v. −.50. This ratio does not differ greatly from the av. ratio of fear 2.60 (av. m.v. −.64) as shown in the records and in Fig. 4. In 'fear,' we find a gradual lengthening of the curve in some cases, while in others there is a slight inspiratory pause. L. B.'s fear breathing curve is somewhat similar to her 'wonder' breathing curve as shown in Fig. 3, with the difference that 'wonder' has the greater inspiratory pause. Fear with a decided inspiratory pause is a complex emotion which may

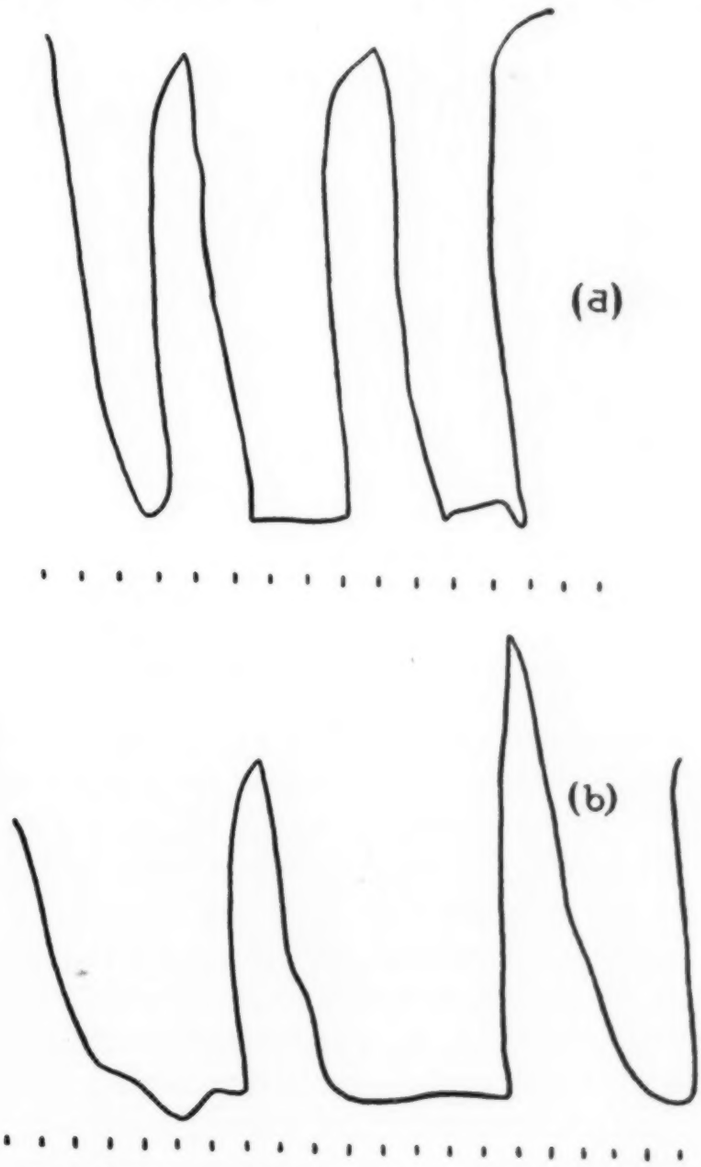


FIG. 3. Breathing Curve During Wonder. (*a*) Subj. L. B.—I. : E. = −1.64 units; depth 45 units; rate of work per sec. 8.68 units. (*b*) Subj. D. L'E.—I. : E. = −2.25 units; depth 33 units; rate of work per sec. 4.19 units.

be either fear and shock, fear and wonder, or fear and surprise. (The breathing curve of 'surprise' is similar to that of wonder.) However, the rate of work differs in the two emotions. There is much less respiratory work done during 'wonder' than during 'fear,' but if the inspiratory pause is introduced into the 'fear' breathing curve, the rate of work per sec. will be equivalent to that of 'wonder.'

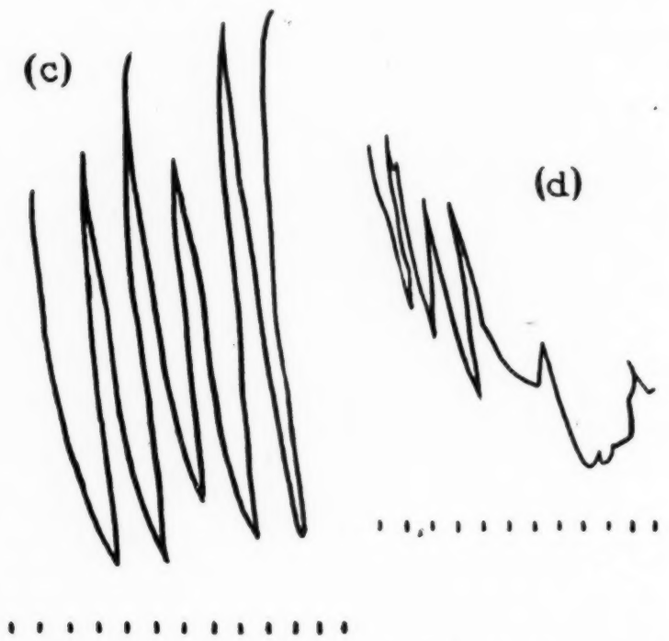


FIG. 4. Breathing Curve During Fear. (*c*) Subj. M. M.—I. : E. = 2.55 units; depth 41.8 units; rate of work per sec. 23.20 units. (*d*) Subj. F. M.—I. : E. = 2.19 units; depth 17.15 units; rate of work per sec. 10.14 units.

In 'pain,' the average ratio is 1.546 (m.v. −.398). Five subjects give more time for inspiration than expiration, while one subject gives less time. Subj. F. M. does 3.74 units of work per sec., while L. B. does 14.62 units per sec. The rate of work depends not only upon the amplitude, but also upon the respiratory pause. Fig. 5 shows the inspiratory pause in F. M.'s pain breathing curve which lessens the rate of work per sec. I. M.'s curve shows five respirations in 21 sec., while L. B.'s curve shows five respirations in about 10 sec. Thus it seems that the rate of work also depends upon the rapidity of the breathing phases.

In "pleasure" the average ratio is 1.11 (m.v. −.15).

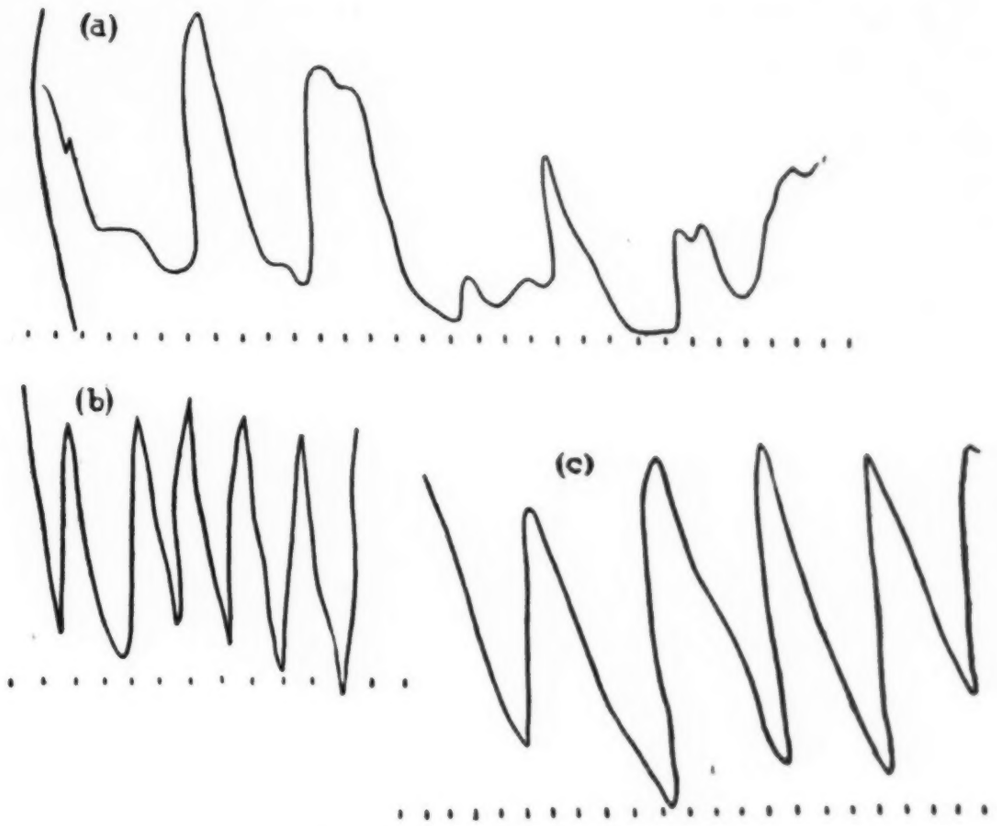


FIG. 5. Breathing Curve During the Emotion of 'Pain.' (*a*) Subj. F. M.—I. : E. = −1.7; depth 22.4; rate of work per sec. 3.74 units. (*b*) Subj. L. B.—I. : E. = −.78; depth 27.8; rate of work per sec. 14.62 units. (*c*) Subj. I. M.—I. : E. = −1.97; depth 34.–; rate of work per sec. 9.03 units.

FIG. 6. Breathing Curve During the Emotion of Pleasure. (*a*) Subj. D. L'E.—I. : E. = 1.26; depth = 34.2; rate of work per sec. = 7.55. (*b*) Subj. L. B.—I. : E. = 1.20; depth = 29.4; rate of work per sec. = 12.33.

As in pain, five subjects give more time to inspiration than to expiration, while subject I. M. gives more time to expiration. Fig. 6 shows D. L'E.'s curve: five respirations in about 15 seconds (rate of work per sec. 7.56); and L. B.'s curve: five respirations in about 9 seconds (rate of work per sec. 12.33).

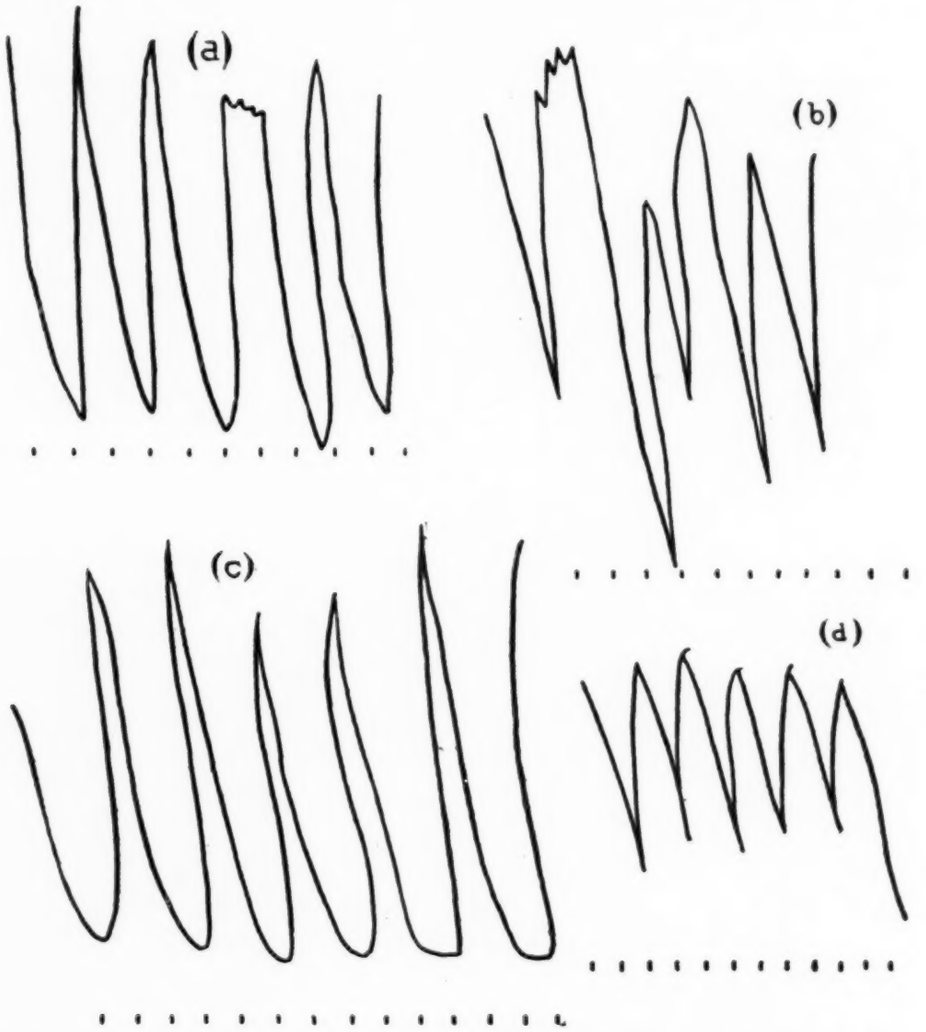


FIG. 7. Breathing Curve During the Emotion of Anger. (*a*) Subj. A. F.—I. : E. = 1.87; depth = 36.2; work per sec. = 17.32 units. (*b*) Subj. M. M.—I. : E. = .84; depth = 32.3; work per sec. = 10.82 units. (*c*) Subj. D. L'E.—I. : E. = 1.72; depth = 38.1; work per sec. = 15.13 units. (*d*) Subj. L. B.—I. : E. = .52; depth = 18.1; work per sec. = 9.41 units.

In 'anger' four subjects give more time to inspiration, while two subjects give more time to expiration. Av. ratio = 1.48 (m.v. −.57). The rate of work varies from 9.41 per

sec. to 17.32 units per sec. This irregularity is caused by a slight inspiratory or expiratory pause due to swallowing or clenching the fists; to lack of uniformity in the amplitude; and to the breath rate, as shown in the records and in Fig. 7.

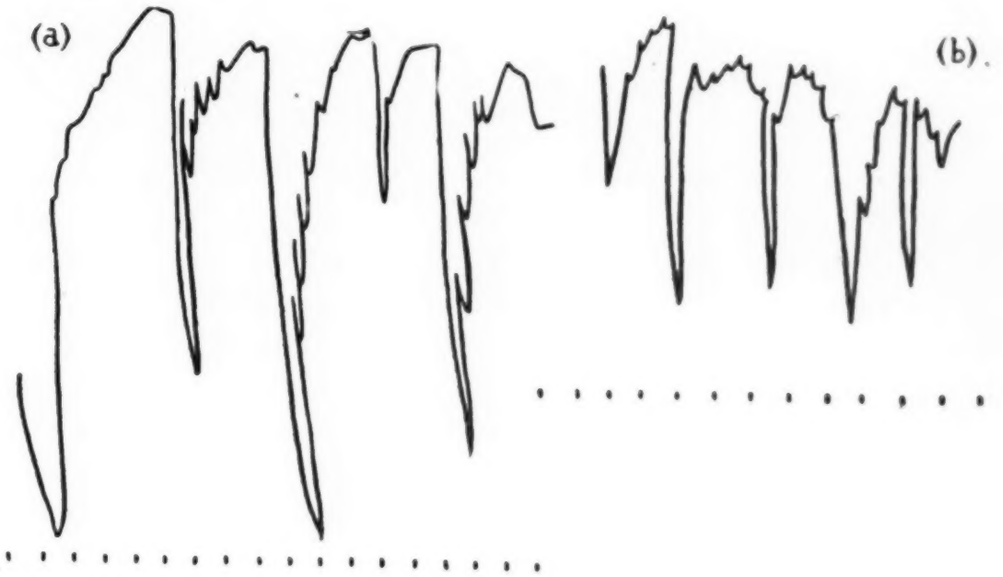


FIG. 8. Breathing Curve During the Emotion of Laughter. (*a*) Subj. D. L'E.—I. : E. = .22; depth = 30.6 units; rate of work per sec. = 9.- units. (*b*) Subj. M. M.—I. : E. = .34; depth = 21.65 units; rate of work per sec. = 11.66 units.

Both laughter and hatred have characteristic breathing curves as shown in Fig. 8 and Fig. 9, as well as in Plates IV. and V. In laughter I. : E. = −.30 units (m.v. −.06); and in hatred I. : E. = −.515 (m.v. −.24). It seems that the subjects were a little more successful in the expression of laughter than in the expression of hatred. However, both show a decided respiratory pause.

SUMMARY

In normal breathing, the average time of the inspiration as compared with that of expiration is about as 4 : 5 (.805). That is, the time for inspiration is less than the time for expiration. This is also true for laughter (.30) and hatred (.515). In disgust (1.08); pleasure (1.11); anger (1.48); pain (1.546); wonder (2.49); and fear (2.66), the average time for inspiration is greater than the time for expiration.

When we compare the average rate of respiratory work per second for the six subjects with each individual record, we find great variability, due, perhaps, to the lack of uniform stimuli, to the lack of uniform intensity; as well as individual

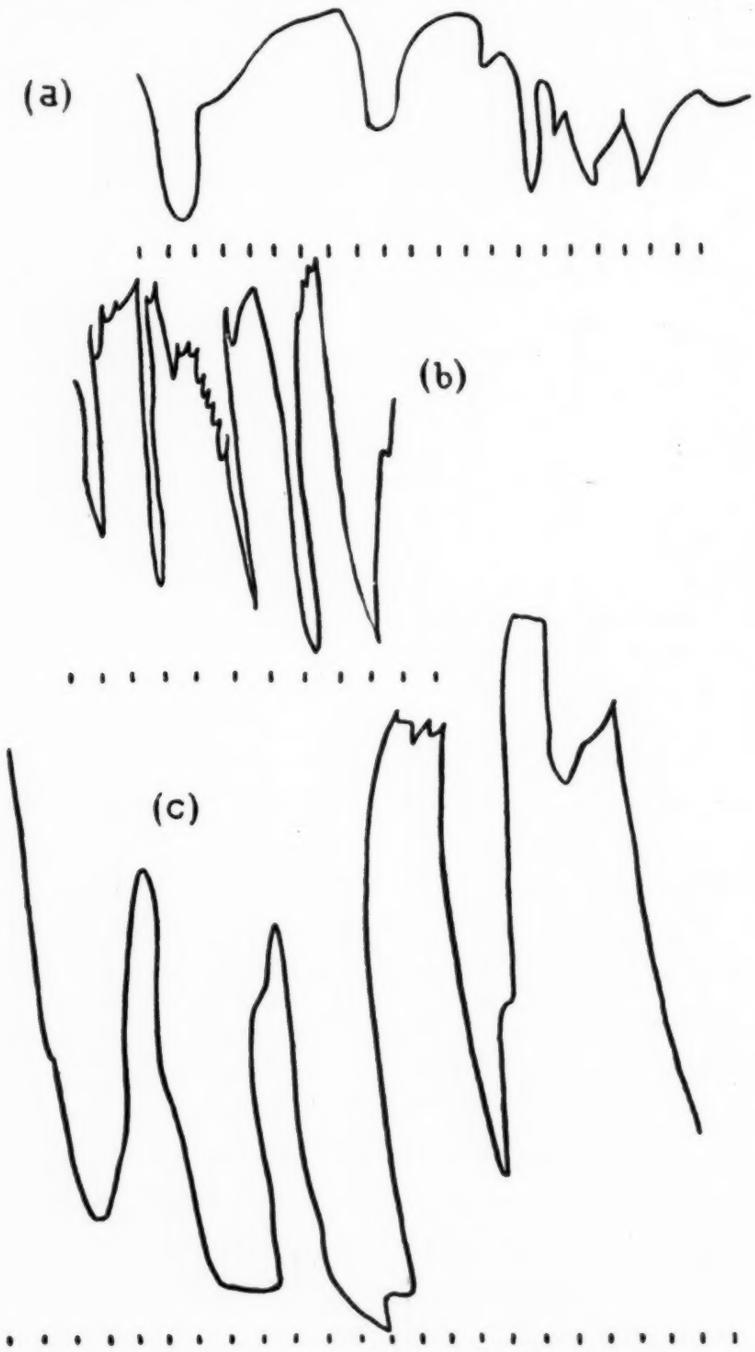


FIG. 9. Breathing Curve During the Emotion of Hate. (*a*) Subj. L. B.—I. : E. = .49 units; depth = 10.4 units; work per sec. = .88 units. (*b*) Subj. M. M.—I. : E. = .99 units; depth = 30.08 units; work per sec. = 16.25 units. (*c*) Sub D. L'E.—I. : E. = .45 units; depth = 37.80 units; work per sec. = 9.60 units.

differences. Although irregularities are found, there seems to be a tendency to do much less work in wonder and disgust than in anger and fear; and less in pain than in pleasure. These facts do not contradict the data of ordinary observation. James has pointed out that 'fear has bodily expressions of an energetic kind, and stands, beside lust and anger, as one of the three most exciting emotions of which our nature is susceptible.'[1] In wonder, we have an inspiratory pause which lessens the rate of work per sec.; while in hate we have the expiratory pause which also lessens the rate of work per sec. In disgust, the rate of work depends upon the depth of the first inspiration followed by an expiration, and the great inhibition of the following respirations. It is interesting to note that pleasure and pain appear side by side in order of work done per second.

Check No. 1.—As great irregularities were found in the depth of the curve, we have arbitrarily calculated the rate of work per second with an amplitude of one unit. Tables IV. and V. allow a comparison of results for the six subjects in order of respiratory work done per sec. with the original average, and when calculated with a depth of one unit.

TABLE IV

	Av. Depth	Av. Work per Sec.
Fear	33.19	14.57
Anger	31.78	13.30
Pleasure	27.26	9.465
(Laughter)	(26.55)	(8.42)
Pain	29.65	8.028
(Hate)	(28.42)	(7.46)
Wonder	38.58	6.39
Disgust	15.31	5.93
Normal	13.89	4.67

Thus we find more work accomplished during 'fear' and 'anger' than during 'wonder' and 'disgust'; and more work done during pleasure than during pain. However, the 'normal' and 'disgust' rates have changed positions. The 'normal' holds the seventh rank in Table IV., while it has

[1] Wm. James, "Principles of Psychology," Vol. II., p. 415.

the fifth position in Table V. Disgust, which has the sixth position in Table IV., occupies the third position in Table V. All that we can say is that when we calculate the rate of work with an amplitude of one unit, we ignore the form of the curve. Both the 'normal' and 'disgust' breathing curves possess characteristic forms, as may be seen in Figs. 1 and 4, as well as in Plate II.

TABLE V

	Depth Taken Arbitrarily	Rate of Work per Sec.
Fear	1 unit	.4389 units
Anger	1 "	.4185 "
Disgust	1 "	.3873 "
Pleasure	1 "	.3475 "
Normal	1 "	.3363 "
(Laughter)	(1 unit)	(.3167)
Pain	1 "	.2707 "
(Hate)	(1 ")	(.2625)
Wonder	1 "	.1656 "

The 'fear,' 'anger,' 'pleasure,' 'pain,' breathing curves have similar forms, and for that reason did not change their positions in order of work done per second, but were merely displaced by the 'normal' and 'disgust' breathing curves. This also holds true for 'wonder,' 'hate,' and 'laughter' which are similar in respect to having either an inspiratory or expiratory pause which lessens the rate of work per second.

Check No. 2.—In order to partly check up these results, we had A. F. pose before the camera, while the breathing movements were recorded on the revolving drum of Porter's kymograph and the time recorded by Jacquet's chronometer.

The directions given were the same as those mentioned in experiment: "Look at a stated point, then look quickly into the camera and express the various degrees of (1) pleasure culminating in laughter, (2) anger culminating in hatred, and the various degrees of disgust, pain, wonder and fear." As soon as A. F. heard the second click of the camera, the second degree was assumed. The following photographs, breathing curves, and figures speak for themselves much better than any discussion might do.

Unfortunately all the scales are not as perfect as desired, due to fatigue and other disturbances. The error of execution may also be due 'partly to an error of movement;[1] and partly also to an error in the intention'[2] (quoted from 'Elements of Exper. Phonetics,' Edw. W. Scripture, p. 202). Nevertheless, we note that, in the medium degree, more work is done during fear and anger than during pleasure and pain or 'wonder' and 'disgust.' However, although pleasure and pain appear side by side in order of work done per sec., more work is done during 'pain' than during 'pleasure'; and more work is done during disgust than during wonder. These facts do not only contradict our former statement in regard to order of work done per second, but also contradict A. F.'s own record, as may be seen in the following tables.

TABLE VI

SUBJECT A. F. WITH PHOTOGRAPHS (MEDIUM DEGREE)

	I./E.	Depth	Rate of Work per Sec.
Photo 40, Wonder	2.6	10.–	1.77
" 46, Disgust	.63	11.54	7.74
" 58, Pleasure	.93	22.16	10.08
" 52, Pain	1.27	23.1	12.06
" 64, Anger	1.19	22.25	13.68
" 70, Fear	2.16	23.88	14.97

TABLE VII

SUBJECT A. F. WITHOUT PHOTOGRAPHS (MEDIUM DEGREE—SEE ALSO TABLE I)

	I./E.	Depth	Rate of Work per Sec.
Disgust	.85	7.90	4.44
Wonder	3.50	47.–	7.66
Pain	2.–	26.50	8.16
Pleasure	1.05	24.–	9.42
Anger	1.87	36.20	17.32
Fear	3.31	22.30	15.68

It is self-evident that a 'wonder' breathing curve which gives I. : E. = 2.6 and depth of 10 units will give different results when calculating the respiratory work done per sec.,

[1] Fullerton and Cattell, 'On the Perception of Small Differences,' 65, Philadelphia, 1802.

[2] Woodworth, 'Accuracy of Voluntary Movement,' *Psy. Rev.* Monogr. Suppl. III., No. 2, 71.

than the 'wonder' breathing curve which gives I. : E. = 3.50 units and a depth of 47 units. The same may be said of the breathing curve of 'disgust.' All this merely emphasizes the fact that we may expect to find as great a mean variation around the subject's own average, as around the average of a great number of observers. We may, therefore, for the present, consider our first conclusions as valid. (See Tables II. and IV.) And, as there is uncertainty and lack of uniformity is there need of further experiments, with many trials for each subject.

It is interesting to note that in the small space, known as the face, we find assembled almost all the senses of the body, for the special senses are certainly present. Without words we may read the emotions of wonder, disgust, pleasure, pain, anger and fear. We also see the natural association between the muscles of respiration and that of the face (muscles of expression), for the mouth and nose are the respiratory organs (air passages) which carry the air to the closed cavity, known as the chest. We may safely say with Bell and Mosso thae the emotions are principally reflected in the muscles of the face and that of respiration. The various emotions have characteristic expressions, and thus naturally we should expect corresponding changes in the respiratory apparatus.

PLATE I

	37 38	39 40	41 42	
		I./E.	Depth	Work per Sec.
Attention (37)		1.25	19.5	9.74
Wonder (38)		3.55	20.–	6.3
" (39)		20.33	25.	4.98
" (40)		2.6	10	1.77
" (41)		6.8	21.–	3.24
" (42)		6.44	27.–	4.83

PLATE II

	43 44	45 46	47 48	
		I./E.	Depth	Rate of Work per Sec.
Attention (43)		1.01	18.5	11.81
Disgust (44)		.79	15.3	8.79
" (45)		.67	13.	8.03
" (46)		.63	11.54	7.74
" (47)		.44	15.58	6.93
" (48)		.08	31.5	5.55

PLATE 1.

37 38 39 40 41 42

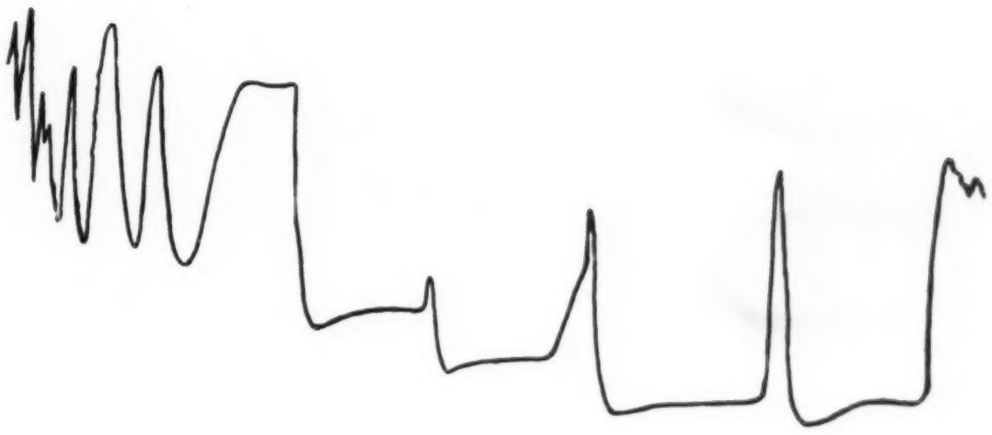


PLATE 2.

43 44 45 46 47 48

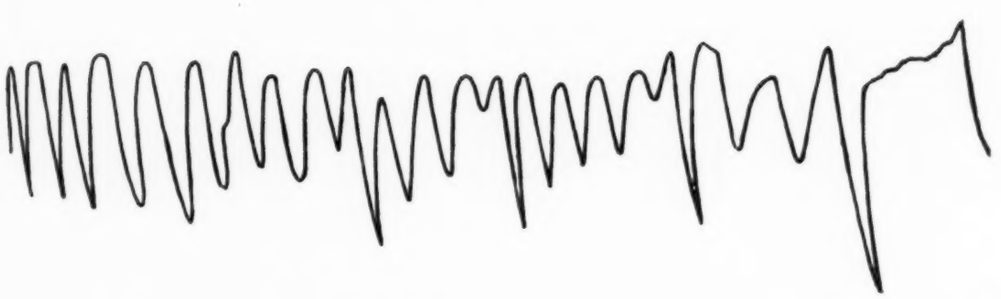


PLATE 3.

49 50 51 52 53 54

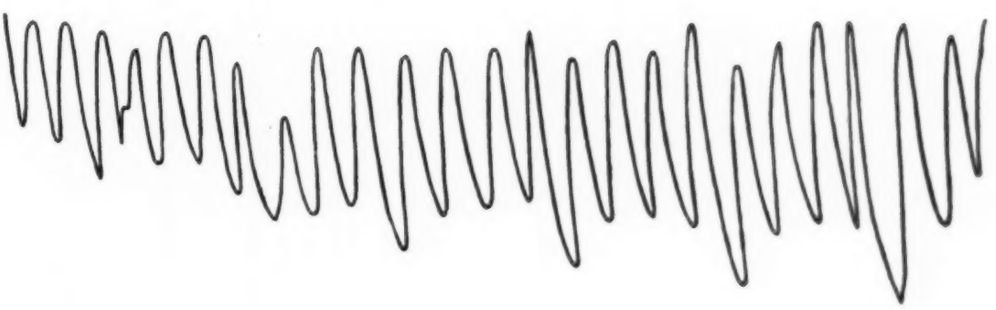


PLATE 4.

55 56 57 58 59 60

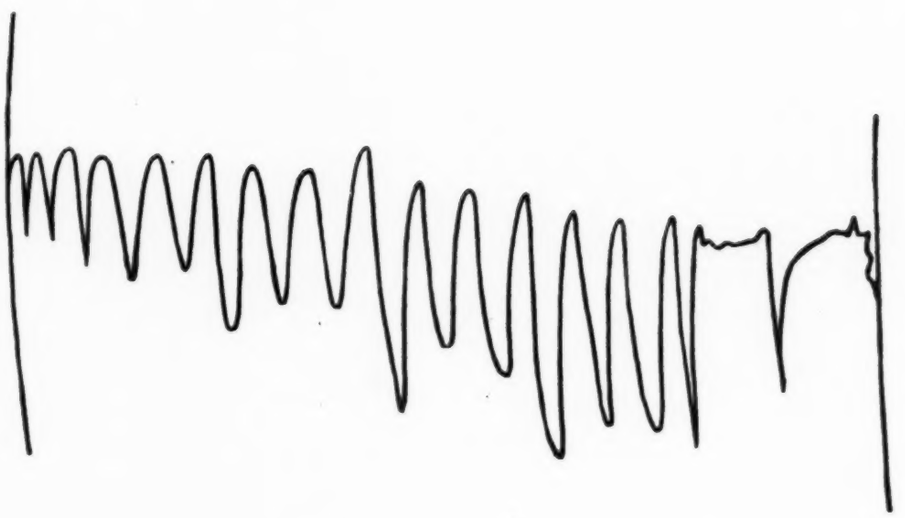


PLATE 5.

61 62 63 64 65 66

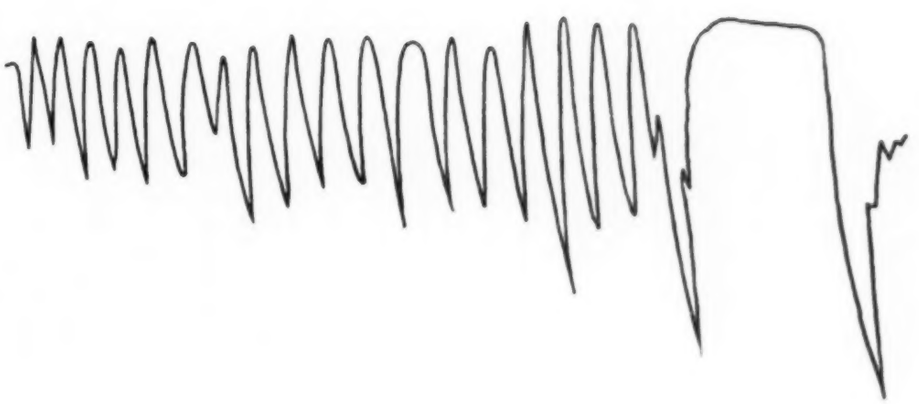


PLATE 6.

67 68 69 70 71 72

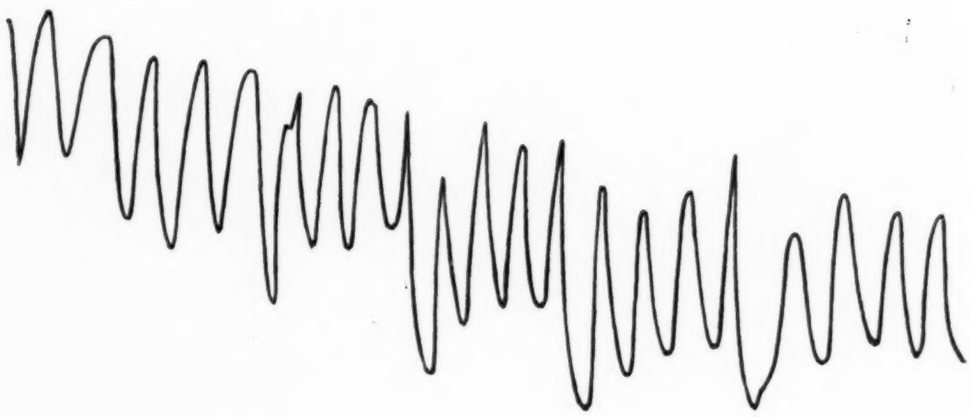


PLATE III

		49 50 51 52 53 54		
		I./E.	Depth	Rate of Work per Sec.
Attention	(49)	.93	15.87	9.19
Pain	(50)	.89	17.63	10.19
"	(51)	1.40	21.25	10.56
"	(52)	1.27	23.1	12.06
"	(53)	1.08	24.63	13.17
"	(54)	1.06	25.33	11.46

PLATE IV

		55 56 57 58 59 60		
		I./E.	Depth	Rate of Work per Sec.
Attention	(55)	1.–	11.–	5.50
Pleasure	(56)	1.08	12.–	5.58
"	(57)	1.28	16.–	7.27
"	(58)	.93	22.16	10.08
"	(59)	.94	23.66	10.81
Laughter	(60)	.18	19.75	4.98

PLATE V

		61 62 63 64 65 66		
		I./E.	Depth	Rate of Work per Sec.
Attention	(61)	1.50	16.75	10.70
Anger	(62)	1.34	15.16	10.48
"	(63)	1.32	19.12	12.39
"	(64)	1.19	22.25	13.68
"	(65)	1.12	28.–	18.66
Hatred	(66)	.19	41.5	5.64

PLATE VI

		67 68 69 70 71 72		
		I./E.	Depth	Rate of Work per Sec.
Attention	(67)	.73	17.75	8.62
Fear 1°	(68)	1.43	23.	11.87
" 2°	(69)	2.12	23.63	14.45
" 3°	(70)	2.16	23.88	14.97
" 4°	(71)	2.26	24.25	13.47
" 5°	(72)	1.69	21.375	10.16

A GRADED SERIES OF COLORED PICTURE PUZZLES

BY GRACE HELEN KENT

This test is offered as the second unit of a system of non-verbal tests, the purpose of which has already been stated.[1]

The picture puzzle is well adapted to the general requirements, because it is a game which appeals strongly to persons of all ages. The interest which many adults manifest in difficult jig-saw puzzles is well known. I have seen a boy of three years work very diligently to solve a puzzle made from a highly colored picture, and in the series of tests here reported I have used two subjects only five years of age.

I have found picture puzzles useful in the study of insane subjects, especially advanced cases of dementia præcox. The puzzles had not been standardized, and were used as a means of gaining the coöperation of unresponsive patients or as a reward for the performance of a less attractive task rather than for purposes of systematic observation.

In the spring of 1915 I attempted to use picture puzzles in the study of defective children, but with little success. The puzzles which had been so popular among insane patients proved to be far too difficult for children of low grade intelligence, and I was unable to find pictures from which puzzles sufficiently simple could be made. The difficulty of obtaining suitable pictures is a surprisingly serious objection to the use of picture puzzles as a test method.

The test may be made indefinitely difficult, either by cutting the picture into many small pieces or by imposing a time limit. But it cannot be made indefinitely easy without increasing the possibility of solution by chance. If, therefore, a series of puzzles is to be graded in difficulty, the plan of construction should be formulated with reference to the lower end of the scale.

[1] 'A Graded Series of Geometrical Puzzles,' JOURNAL OF EXPERIMENTAL PSYCHOLOGY, Vol. I., p. 40.

In the course of many preliminary experiments with puzzles more or less unsuitable, I have found that the following conditions are favorable to prompt solution:

1. The coloring of the picture should be moderately strong. There should be sharp contrasts and clear-cut lines, mainly diagonal.

2. The subject of the picture should be simple, preferably a single figure which contrasts strongly with a comparatively plain background. It should represent something that a very young child will instantly recognize. The ideal picture for the simplest puzzles would be a human face, a human figure in ordinary clothing, a cat, a dog, or a horse.

3. Each piece of the puzzle should be of such size as to be easily handled.

I have not been able to find pictures that satisfy these requirements. Postal cards, unfortunately, are much too small to be serviceable. I have spent many days in New York art shops, and have looked over toy picture books by the score, but have failed to find a single picture perfectly adapted to the purpose. The most satisfactory pictures I have seen were taken from advertisement calendars and cannot be duplicated. It will probably be necessary, before the test can be perfected, to have pictures made for the purpose; but much further experimentation will be needed before suitable pictures can be designed. For the present it seems best to use inexpensive pictures, so as to make the test available to any one who may care to give it a trial.

This series is made wholly from pictures sold by one or both of the following companies: The Perry Pictures Company, Malden, Mass.; and G. P. Brown and Company, Beverly, Mass. I visited the headquarters of both companies, so as to have an opportunity to examine every colored picture on their lists, and selected about one hundred pictures which possessed no very obvious defects. The more unsuitable of these have been eliminated by two independent series of tests[1] and the number has been reduced to twenty.

[1] In making the preliminary tests I have been assisted by Celia H. Sheldon, and I gratefully acknowledge my indebtedness to her.

Few of them represent scenes familiar to the average American child, and they are far from satisfactory. They are offered mainly on the ground that they are obtainable in any quantity at a cost of two or three cents apiece.

Each puzzle is made by cutting the picture or pictures into horizontal strips. In this system of tests it is my aim to keep different variables separate, as far as possible, and to deal with one at a time. Irregularities of form have no place in this test, which is primarily a test of color matching. Apart from theoretical considerations, I have empirical evidence that such irregularities tend to make a picture puzzle more difficult as well as more complex. In my early experiments upon insane subjects I cut many pictures irregularly, in some cases following the lines of the picture; but I found that these puzzles required more time for solution than those which were cut into plain strips or blocks.

The pictures are of approximately the same size, about fifteen by twenty centimeters. The width of the strips varies for different puzzles, but all the strips of a given puzzle are of equal width. The pictures should be mounted on moderately heavy cardboard. This may be done very easily by laying a sheet of rubber tissue between the picture and the cardboard and then passing a warm flatiron over the picture, protecting it from direct contact by a sheet of tissue paper. All the borders of the pictures should be trimmed. Detailed instructions for cutting each picture are given in the table.

The more difficult puzzles consist of two or three similar pictures, but any of these may be used singly if desired. The simplest puzzles of the series consist of three pieces each. The three two-piece puzzles are not intended for general use, and for this reason they are not numbered as a part of the series. They may be given to a subject of low grade intelligence who is unable to solve any of the three-piece puzzles. In view of the very considerable possibility of solution by chance, the subject should be required to solve all three of the two-piece puzzles in order to receive credit for any.

Because of the unfamiliarity of the scenes represented

in the pictures, it is well to show the subject a whole picture before giving the puzzle pieces. I do not require the subject to look at the picture for a specified number of seconds, but am careful to be sure that he gives attention to it. The pieces are presented in a pile, each piece with the picture side up but with about half the pieces reversed end for end. The subject is thus required to turn some pieces around, but not to turn them over. The pieces should be mixed with some care and then they may be numbered on the back, so that they can be given to all subjects in the same order. The time required for the solution of a puzzle is measured by a stop watch and recorded in seconds.

Number of Puzzle	Name of Picture	Catalogue Number, Perry Pictures Co., Malden, Mass.	Catalogue Number, G. P. Brown & Co., Beverly, Mass.	Number of Strips	Distance of First Cut from Top of Picture, in Millimeters	Width of Each Strip, in Centimeters	Time Records of 29 Subjects, in Seconds		
							Minimum	Median	Maximum
A	Napoleon	.....	91	2	0	10			
B	Gopher	9,308	6,308	2	0	10			
C	European Squirrel	9,296	6,296	2	0	10			
1	Scarlet Ibis	9,322	.....	3	15	6	3	6	12
2	Gray Rabbit	9,174	6,174	3	0	5	3	6	15
3	American Blue-Jay	9,011	6,011	3	5	6	3	7	27
4	See! The Conquering Hero Comes	.....	13	4	0	5	5	10	35
5	Domestic Horse	9,494	6,494	3	0	5	6	17	64
	Domestic Cow	9,487	.....	3	3	5			
6	Baby Stuart	.....	4	3	10	6	6	16	104
	Miss Simplicity	.....	14	3	20	6			
7	Zebra	9,456	6,456	4	0	4·5	11	23	94
	Giraffe	9,447	6,447	4	18	4·5			
8	Sandhill Crane	9,224	6,224	4	2	5			
	Clapper Rail	9,307	6,307	4	2	5	13	60	206
	Bartramian Sandpiper	9,147	6,147	4	2	5			
9	Forests	9,273	.....	5	0	4	23	52	218
	The Three Birches	.....	35	5	0	4			
10	Just a Little More	.....	103	6	8	3	69	187	504
	Helping Mother	.....	102	6	8	3			

The puzzles are numbered approximately in the order of difficulty, as indicated by the results of preliminary tests.

An additional series of tests has been made upon thirty-two subjects, but three of the records are omitted because of errors. The table shows the extreme and median time records obtained from twenty-nine subjects.

When the test is used for the study of individual cases it will probably be necessary to set an arbitrary time limit. For the convenience of the examiner, I recommend that one minute be allowed for each puzzle, regardless of its difficulty. This is a liberal allowance for the puzzles at the lower end of the scale, while it is short enough to insure that the last puzzle will be solved only by a subject of exceptional ability in this line of work. It is not necessary to interrupt the subject at the expiration of the time, nor to let him know that he has failed. It is better to give him a little assistance, so as to enable him to finish without undue loss of time.

A SPECTROSCOPIC APPARATUS FOR THE INVESTIGATION OF THE COLOR SENSITIVITY OF THE RETINA, CENTRAL AND PERIPHERAL

BY C. E. FERREE AND GERTRUDE RAND

Bryn Mawr College

The need has long been felt in physiological and psychological optics for better methods of specifying and standardizing the stimulus. In an adequate specification and standardization of the stimulus for work in these fields, three points are involved. Means must be had (1) of securing a small range of wave-lengths and of stimulating with them any part of the retina; (2) of determining accurately the values of the wave-lengths employed; and (3) of specifying the amounts of light used. In the present series of papers apparatus will be described with which it is, comparatively speaking, easily and conveniently possible (1) to stimulate any part of the retina with the light of the spectrum and to control as desired the conditions of preëxposure and surrounding field; (2) to control the amounts of light used within the small gradations needed for threshold and just noticeable difference determinations; and (3) to specify in C.G.S. units in any case in which it is wished the amount of light used. This work was begun and announced three years ago as the logical completion of work published at that time[1] and has

[1] See Rand, G., 'The Factors that Influence the Sensitivity of the Retina to Color: A Quantitative Study and Methods of Standardizing,' *Psychol. Rev. Monog.*, 1913, *15*, No. 1, 166 pp.; and Ferree, C. E., and Rand, G., 'A Note on the Determination of the Retina's Sensitivity to Colored Light in Terms of Radiometric Units,' *Amer. Journ. of Psychol.*, 1912, XXIII., pp. 328–332.

If more time has been taken to accomplish what we have here to present than seems justifiable, we beg to point out that the work has been in many respects pioneer in character and that the difficulties on the radiometric side had not yet been overcome by the physicist at the time we began our work. We have also been greatly diverted by the pressure of other work.

The apparatus has been greatly simplified from its original construction. As it

involved the construction of a new type of campimeter, spectroscope, apparatus for the regulation of the amount of light used applicable to the spectroscope employed, and radiometric apparatus non-selective in its response to wave-length and sufficiently sensitive for the purpose in hand. The apparatus included under the first three of the above classes was constructed under direction by our department mechanician and should be within the technical capabilities of any good college mechanician. The description of this apparatus will form the subject matter of the present paper. For the radiometric apparatus we are indebted to Dr. W. W. Coblentz, radiometric specialist for the Bureau of Standards. Believing that the sensitivity of the thermopile could be increased by enlarging the area of the receiving surface and wanting to measure for at least one color all the light energy falling on the stimulus-opening in our campimeter screen rather than attempt to calculate it from one or more linear elements in this surface, we took up with Dr. Coblentz the feasibility of constructing surface thermopiles. He was asked to construct for us a surface thermopile having a receiving surface 16 mm. square, a trifle larger than the opening in our campimeter screen.[1] By means of this thermopile and one of the linear type we have been able to measure the light at three places—at the analyzing slit, at the campimeter opening, and at the eye. The use that is made of these measurements in the color investigation will be stated in a later paper.

Description of Apparatus

For the sake of convenience the apparatus may be described under three headings: (*a*) an apparatus for getting

now stands it is comparatively simple in form; it is not difficult to operate, and is, we believe, within the financial and technical possibilities of any laboratory in which serious work is being done in the optics of color. There is no work known to us in the investigation of color sensitivity in which light of a standard quality and intensity is needed to which this or a similar apparatus can not be adapted. On the spectroscopic side at least we hope it will prove sufficiently feasible and practicable to render undesirable the use of colored papers and filters in much of the work that is now being done in the optics of color.

[1] See Coblentz, W. W., 'Instruments and Methods Used in Radiometry'—II., *Bulletin of the Bureau of Standards*, 1912, IX., p. 22, ff.

the light stimulus of spectrum purity and of exposing different parts of the retina to this stimulus under any conditions of surrounding field, preëxposure, etc., that may be desired; (*b*) an apparatus for varying the intensity of the stimulus within the limits needed for threshold and j.n.d. work; and (*c*) an apparatus for measuring the intensity of the stimulus in terms of common or C.G.S. units.

1. An apparatus for getting a light stimulus of spectrum purity and of exposing the different parts of the retina to this stimulus under any conditions of surrounding field, preëxposure, etc., that may be desired.

To design an apparatus which will combine all the above features and which can besides be easily and conveniently operated is a task which has presented considerable difficulty.[1] Dreher[2] and Abney,[3] for example, have each described apparatus devised to accomplish a part of what is outlined above, but the apparatus of neither would at all serve the purpose that has impelled us to take up anew the problem of the construction of apparatus.

[1] A statement of the points needed by an apparatus by means of which all the factors influencing the sensitivity of the retina to colored light may be controlled and which will have besides a wide range of serviceability is, in the belief of the writers, as follows. (1) It must provide an accurate means of separating out the desired ranges of wave-lengths throughout the spectrum. (2) Means must be provided for directing these wave-lengths to any part of the retina that is desired. (3) Provision must be had for controlling the brightness of the field surrounding the color and the brightness of the preëxposure. (4) The apparatus must be available for use in a light as well as in a dark room, else (*a*) the influence of the brightness of the surrounding field and of the preëxposure upon the response of the retina to the different colors can not be eliminated from the investigation when wanted; and (*b*) a large part of the work in the optics of color can not be done, namely, the investigations of response under different degrees of illumination. (5) A method of presenting the light to the eye must be had which will give the effect of a surface or field variable in shape and size that may be imaged on the retina. (6) The method of presentation must be such as to allow of no admixture of light from the room with the range of wave-lengths needed for the stimulus, and it must be as little as possible wasteful of light, else a sufficient range of intensity can not be had. (7) A beam of colored light should be provided of such intensity that its energy value per unit of cross section can be specified when desired at the point of entrance of the light into the eye.

[2] Dreher, E., 'Methodische Untersuchung der Farbentonänderungen homogener Lichter bei zunehmend indirektem Sehen und veränderter Intensität,' *Z. f. Sinnesphysiol.*, 1912, *46*, pp. 1–82.

[3] Abney, W. deW., 'The Sensitiveness of the Retina to Light and Color,' *Philos. Trans. of the Roy. Soc. of London*, 1897, Ser. A, *190*, pp. 155–195.

A schematic representation of the apparatus under this heading is shown in the diagram in Fig. 1. It consists in

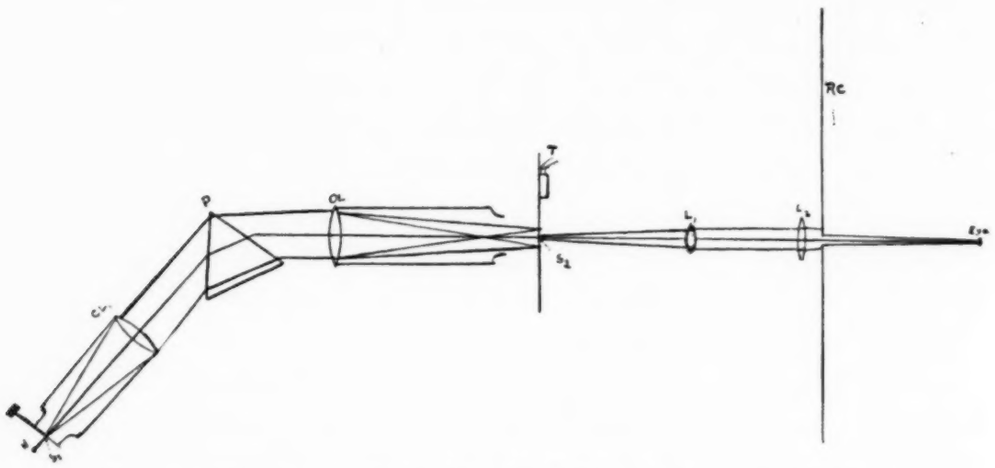


FIG. 1. Showing the Path of the Light from the Source to the Eye.

general of light source (N), spectroscope (Sp), micrometer slit (S_2) for separating out the wave-lengths needed for the colored stimulus, rotary campimeter (RC), collimating lens (L_1) for rendering parallel the beam of light emerging from the analyzing slit (S_2), and focusing lens (L_2) for bringing this beam to a focus on the pupil and for shifting the image formed to follow the pupil as the eye takes fixation at different degrees of excentricity.

It is scarcely needful to call to mind that one of the chief difficulties in devising a peripheral vision spectroscope has been to secure a means of throwing the colored light on the excentric portions of the retina. Dreher, for example, has tried to do this with limited success by holding the eye stationary and by reflecting the light to the different portions of the retina by a system of mirrors. By this means so much light is lost by reflection that the device would be useless for our purpose because we wish to be able to radiometer the light which finally reaches the eye. Moreover the difficulty in making the adjustments and the impossibility of making fine adjustments even for the different portions of the retina in the same meridian render the apparatus practically useless for extended work. Also the ordinary campimeter precautions with regard to the control of the brightness of the

surrounding field and preëxposure can not be taken nor can the apparatus be used in an illuminated room without the admixture of a great deal of light from the room with the wave-lengths selected for the stimulus. So far as we know, no attempt has yet been made to adapt the spectroscope to the campimeter, at least not in such a way that any meridian of the retina can be worked in easily and conveniently from center to periphery and an accurate control be had at every step of the brightness of the field surrounding the stimulus and the preëxposure.[1]

[1] The hollow hemisphere, for example, used by Abney can scarcely be considered a campimeter for it was not designed for exercising any control over the brightness of the surrounding field. The apparatus was designed solely for dark-room work and was called by him a perimeter. The practical impossibility of uniformly controlling the brightness of the field surrounding the stimulus by means of an opaque campimeter screen hemispherical in shape was shown by one of the writers (Ferree) in a previous article. ('A Note on the Rotary Campimeter,' *Psych. Rev.*, 1913, *20*, pp. 373–378.)

Abney describes two devices for exposing the peripheral retina to the light of the spectrum. Both are for use in the dark room. The first consists of a perimeter, the graduated arm of which is painted white, and the following auxiliary apparatus. Below the eye is placed "a small mirror on a ball and socket joint which by means of an arm causes a beam of light falling on it to be cast in any direction that is desired." The monochromatic light for the stimulus is gotten by means of an instrument which he calls his "color patch apparatus." The light passes from this apparatus to the mirror on the ball and socket joint which reflects it to the different points on the arm of the perimeter. In this way patches of color which serve as the stimuli for the eye in the color investigation are formed at different degrees of excentricity on the perimeter arm. That is, with regard to the method of securing the stimulation of the peripheral retina, this apparatus is of the usual type. The eye is held stationary and the retina is stimulated from center to periphery in a given direction by causing the colored stimulus to pass from the center to the periphery of the field of vision in the opposite direction. In his second apparatus, also called a perimeter by him, a hollow white hemisphere made of papier mâché is employed instead of a rotating arm. In the center of this surface is a circular aperture 1½ in. in diameter to admit the stimulus light. To give the effect of a colored surface to this aperture when illuminated from behind with colored light, it was filled in with glass ground on both sides. In order that the shape and size of the stimulus may be varied, additional special apertures are provided which are placed as desired in the path of light immediately behind the fundamental aperture. As before, the color patch apparatus is used as the source of the stimulus light. The method of securing the excentric stimulation of the retina, however, is just the reverse of that described before. That is, the colored stimulus is kept in a fixed position and the eye follows a phosphorescent point which is moved from the center to the periphery of the hemisphere in the meridian in which the investigation is being made.

Neither of Abney's devices would have answered our purposes for the following reasons. (1) Neither is adapted for use in a light room. (2) Provisions for the

One of the difficulties encountered in attempting to do this is that when the eye is turned to take an excentric fixation, the pupil is rotated out of the beam of light. To overcome this, we have taken advantage of the simple fact that when the axis of a double convex lens is displaced from the axis of the beam of light, the image of the light is displaced in the same direction in which the lens is moved. Therefore, by moving the focusing lens (L_2) an appropriate amount in the direction the eye is moved in taking its excentric fixation, the beam of light can always be kept focused on the pupil, while no light energy is lost in the operation, at least not enough to be detected either by the eye or by the thermopiles, linear or surface, that we are now using. That is, in the apparatus shown in the diagram, the lens (L_2) which focuses the light on the eye, is mounted on a rack and pinion operating in the line of the fixation-arm of the campimeter. When a given meridian is to be investigated, the fixation-arm is turned into this meridian and the light is always kept focused on the pupil of the eye by means of fine changes in the position of the lens made possible by the rack and pinion adjustment.[1]

control of surrounding field and preëxposure are lacking. And (3) the loss of light is so great and the method of presentation is such that the intensity of the light entering the eye could not be measured.

[1] One of the objects in devising this means of presenting the stimulus light to the eye has been to get an apparatus that could be used in a well illuminated room, for only under these conditions, as has been shown in previous articles (see 'A Note on the Determination of the Retina's Sensitivity to Colored Light in Terms of Radiometric Units,' *Amer. Jour. of Psychol.*, 1912, *23*, pp. 331–332; 'The Effect of Changes in the General Illumination of the Retina upon its Sensitivity to Color,' *Psychol. Rev.*, 1912, *19*, pp. 463–490; 'The Factors that Influence the Sensitivity of the Retina to Color; A Quantitative Study and Methods of Standardizing,' *Psychol. Rev.* Monog., March, 1913, pp. 135–166) can the influence of the brightness of the surrounding field and of the preëxposure be eliminated from the investigation. Obviously a serious difficulty in working in an illuminated room is to get a method of presenting the stimulus to the eye that will give the effect of a colored field and prevent the admixture of light from the room with the wave-lengths which are needed for the investigation. The following methods may be used in dark-room work to get the effect of a colored field or surface to image on the retina. (1) Light of the desired range of wave-lengths is allowed to fall on a diffusely reflecting surface which is non-selective in reflection of wave-length. The standard reflecting surface for purposes of this kind is prepared from magnesium oxide deposited from the burning metal. Such a surface properly prepared has a high reflection coefficient approximately 90 per cent., and possesses

The Source of Light.—The requirements of a source for our purpose are (*a*) that it should give a light in which all the wave-lengths are represented in sufficient strength both for the needs of the investigation of color sensitivity and for radiometric standardization; and (*b*) that the light emitted shall be as constant as possible in intensity and spectro-radiometric composition. After trying many light sources we have finally adopted as best for our purpose the Nernst filament. This filament, after having been properly seasoned,

the additional advantage that it can easily be kept fresh. And (2) light of the desired composition is allowed to fall on a diffusely transmitting surface also non-selective, or approximately so, in its transmission of wave-length. These methods of getting the effect of a colored surface or field while serviceable within limits for dark-room work, have the following objections for our purpose. (*a*) Both kinds of surface would reflect the white light of the room—the magnesium oxide surface, for example, would reflect approximately 90 per cent. of the light falling on it. This effect, however, is reduced to a minimum by using a double convex lens in the manner employed by us. For when a parallel beam of light falls on the lens and the eye is placed at the focus, the lens fills uniformly with light, and, so far as we are able to determine, white light is not reflected to the eye from the surface of the lens in appreciable amounts under the conditions obtaining in our work. That is, the lens is placed 2.5 cm. behind the stimulus-opening and the whole spectroscope and lens system are enclosed up to the campimeter screen in a light-tight compartment. Under these conditions by exercising a little care in the selection of the position of the apparatus with reference to the distribution of light in the room, so little light is reflected from the lens to the eye that the presence of the lens can not be detected when the eye is in position before the stimulus-opening and no colored light is coming from the spectroscope. In other words, not enough white light is reflected from the lens to render it visible to the eye. (*b*) Both of these methods are very wasteful of light. That is, there is not only a comparatively high percentage of absorption of light by the types of diffusing media, but only a small percentage of the light coming from any point or unit of the surface of these media enters the pupil of the eye. Thus there is not the possibility of getting the wide range of intensities of light needed to give the apparatus maximum serviceability for the investigation of color sensitivity. Furthermore, we are desirous of being able to specify in radiometric units the amount of light per unit area in the cross section of the beam of stimulus light at its entrance into the eye. This would be a very difficult task indeed with either of the two methods of presenting the stimulus light to the eye mentioned above. Its accomplishment, however, is not at all difficult by the method we have adopted. That is, instead of the light spreading from the stimulus-opening as if emanating from a source, it is concentrated into an image on the pupil of the eye, an image in this case of the analyzing slit. (S_2, see pp. 250, 261 and Figs. 2 and 3.) The amount of energy concentrated into this image can easily be determined by direct measurement with our radiometric apparatus for any of the wave-lengths used by us as stimuli, and the amount per unit area be estimated; further, if an artificial pupil were used, or the substitute to be described in a later paper, see *Psychological Review*, 1916, September number, the total amount of light entering the eye could be determined in C.G.S. units.

gives a light which changes comparatively little through long intervals of time. It has the advantage, moreover, that its shape well adapts it for use with the slit of the spectroscope, *i. e.*, the shape is such as to make it possible to utilize for the illumination of the face of the prism a relatively large proportion of the light emitted. Also by increasing the length of the filament and collimator slit, it is possible to increase in direct ratio the amount of light falling on the face of the prism. When in use, in order that no light shall be lost in passing through one or more condensing lenses, the filament

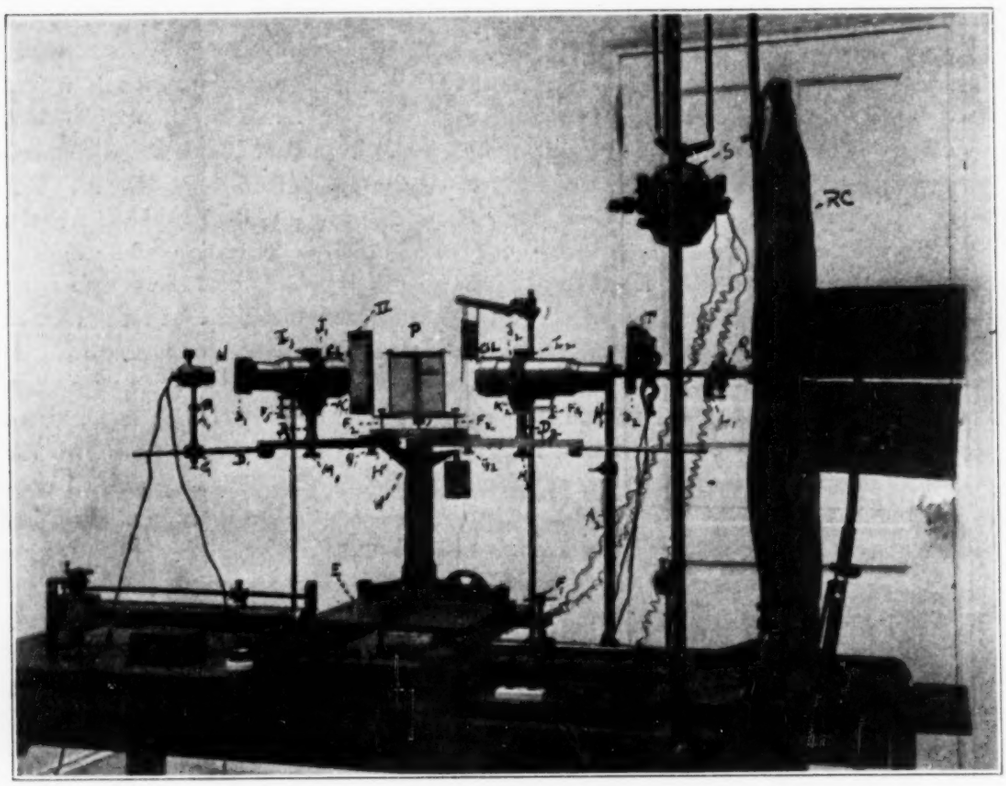


FIG. 2. Showing the Apparatus Grouped for Work—light source, spectroscope, thermopile, and rotary campimeter with its auxiliary lens system. In order that all stray light either from the general illumination of the room or by reflections from the Nernst glower be eliminated, the spectroscope and lens system are, when in use, enclosed from just in front of the Nernst to the campimeter screen in a light-tight compartment.

is mounted as closely as possible to the jaws of the slit. It is shown in position for work at (*N*) in Figs. 2 and 3. The filament is mounted in a lamp socket fastened to an upright

(A_1). In order that the height of the filament shall be adjustable this upright consists of a short rod sliding in a tube fitted with collar and set screw (B) which permits of a movement of the socket up and down, also to right and left. The upright (A_1) is fastened to the horizontal support (D_1) ex-

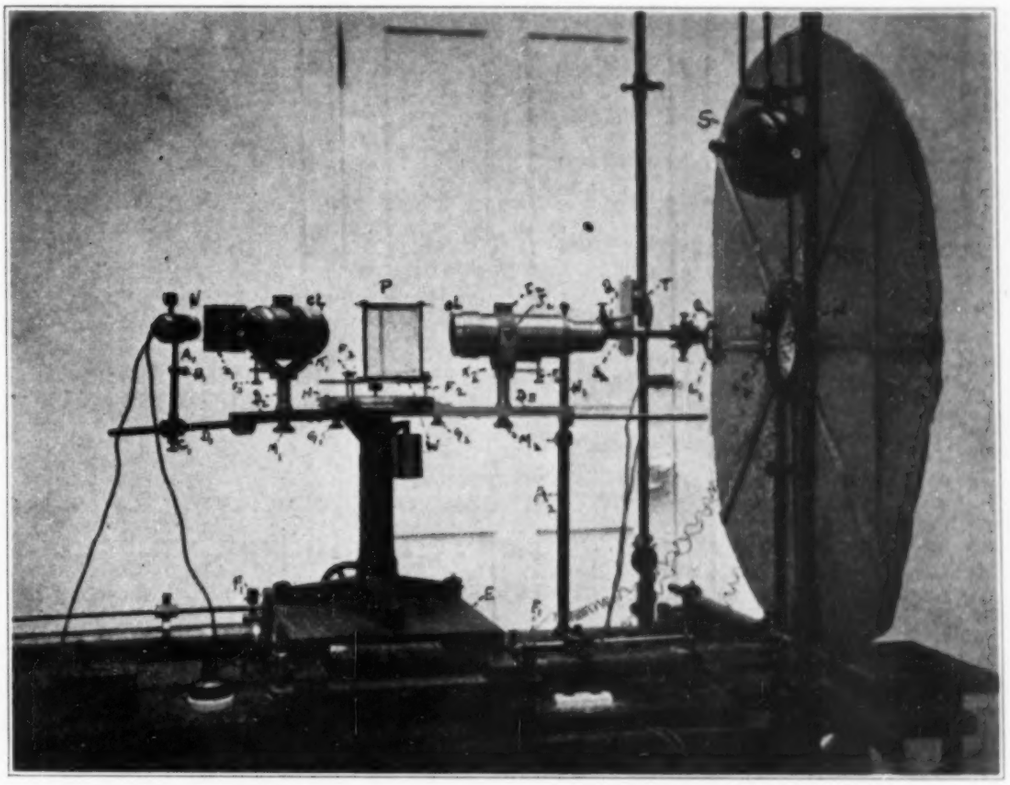


FIG. 3. Showing a Second View of the Apparatus Grouped for Work.

tending out from the collimator arm of the spectroscope by a clamp and set screw (C_1) which permits of the motion of the socket to right and left and to and from the collimator slit. The Nernst filament used by us is designed to be operated at 110 volts on a D.C. current, and has a carrying capacity rated at 1.2 amperes. When operated at its maximum capacity on a direct current, we have found, however, that the life of the filament is short. Satisfactory results have been obtained by us only when it is operated at or below 0.6 amperes. In series with the ballast, therefore, which is ordinarily used for the reduction of the current from the line and to compensate for the change in the resistance of the

Nernst material as its temperature varies, we have found it necessary to use additional resistance. This resistance is needed not only to cut down the current to the desired value, but to correct for fluctuations in the line. Two coils are employed, one coarse and one fine. The former is used to cut down the current to approximately the desired value, and the latter to correct for the fluctuations in the line. Both are in the form of adjustable rheostats. The second is of special construction to give the small changes needed. It consists of a cylindrical coil of wire wound on an insulated core of brass tubing and is operated by a screw motion in such a way as to give the effect of a slider on a single wire. This rheostat is described in greater detail on p. 275. It is not on the market but can readily be constructed to order by a laboratory mechanician. The finely graduated control afforded by it not only makes it possible to correct for fluctuations in the line, as is stated above, but also to compensate for the slow decrease in the carrying capacity of the Nernst material with use. The current consumed is measured by a Weston ammeter graduated to 0.02 amperes. Operated with this type of control the light flux obtained from the Nernst may be kept constant within the limit of change that can be detected either by the radiometer or the eye.

The Spectroscope.—In addition to the usual features attaching to a good spectroscope, our instrument was designed especially to meet the following needs. (1) To answer all the purposes for which a source of colored light may be used in the investigation of color sensitivity, a wide range of intensity is needed. In order too that an adequate radiometric standardization be made, it is especially desirable that light of high intensity be available. (2) If the spectroscope is to be used in conjunction with a campimeter, it is necessary that the objective arm remain in a fixed relation to the stimulus-opening of the campimeter screen and that some convenient and accurate means be had of changing the wave-lengths without changing the position of the objective. The first of these needs was met by employing a collimator slit long enough to admit the amount of light needed, and a

prism and lenses large enough to take care properly of the amount of light admitted. The second point has been met by us in the two following ways, one of which is technically more correct perhaps than the other. (*a*) The spectroscope was mounted on a stationary base supported by levelling screws. In fixed relation to this base a slit (S_2) was permanently mounted to separate out the wave-lengths which are to fall on the stimulus-opening in the campimeter screen. In order to be able to change the wave-length of the light falling on the slit (S_2) the stationary base carries a track along which the whole spectroscope may be shifted by very small amounts. This movement is made by means of a screw of fine thread turned by a wheel $4\frac{1}{2}$ inches in diameter. This track and the base of the spectroscope carry a Vernier scale graduated to 1/50 of a mm. by means of which any previous setting may be accurately reproduced, and in terms of the readings of which the spectroscope may be calibrated in wave-length. This method of changing wave-length not only provides abundantly for small changes in wave-length but it obviates any necessity for readjustment of the collimator arm which would be the case were the wave-lengths changed, for example, by rotating the prism. In case the wave-length is changed by this device, the prism is set for minimum deviation for the D-line, and this adjustment is kept throughout. An adjustment which gives minimum deviation for the D-line alone is generally considered by spectroscopists to be adequate for the work in the visible spectrum when the light is passed through only one prism. Kayser, for example, says:[1] "Bei den Apparaten mit nur einem Prisma verzichtet man für gewöhnlich darauf, alle Wellenlängen unter dem Minimum zu beobachten, sondern stellt das Prisma fest auf, so dass etwa die D-Linien unter dem Minimum durchgehen. Die Dispersion ist bei einem Prisma so gering, dass dies gewöhnlich genügt. Das ist aber nicht mehr der Fall, wenn man über die Grenzen des sichtbaren Spectrums hinausgeht, und so hat vielleicht zuerst Langley bei seiner Untersuchung des ultrarothen Theiles

[1] 'Handbuch der Spectroscopie,' Bd. I., p. 510.

des Sonnenspectrums an einem Apparat mit einem Prisma eine Vorrichtung beschrieben, welche automatisch das Minimum erhält, und welche wegen ihrer Einfachheit seitdem oft verwandt wird." (*b*) In order that minimum deviation may be had automatically for all wave-lengths falling on our analyzing slit, one of our spectroscopes was built with a minimum deviation attachment.[1] A schematic representation of this attachment and the prism in position for use is shown in Fig. 4. In this figure, *P* represents the prism so placed on the prism table that its refracting angle is bisected by one of the radii of the table; *PB* and *PA* represent respec-

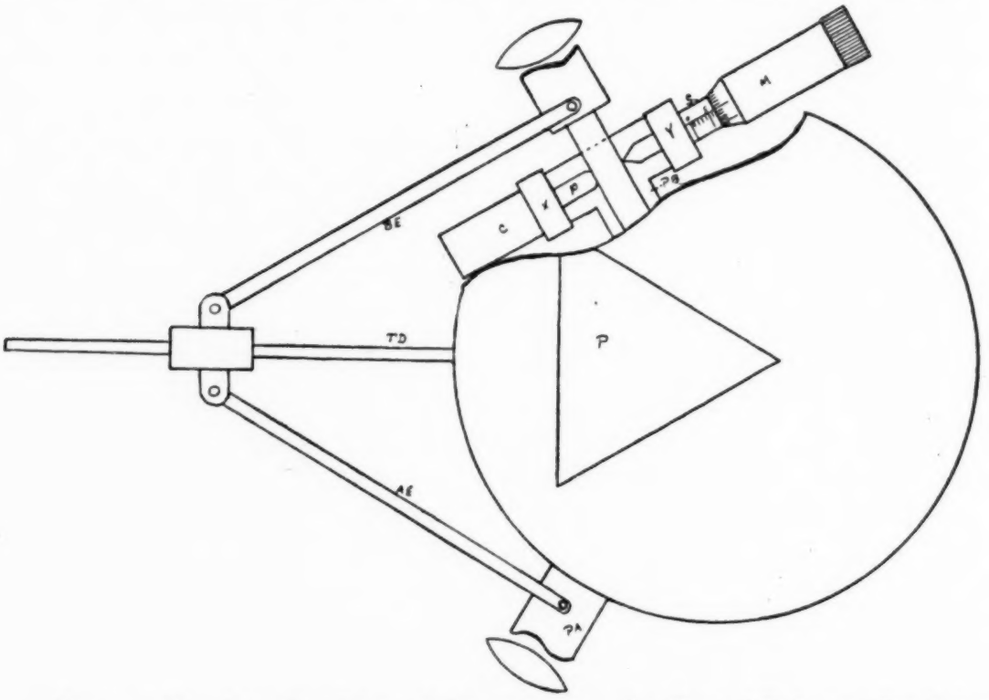


FIG. 4. Showing the Prism Table with Its Auxiliary Minimum Deviation Attachment.

[1] This attachment is a modified form of a device apparently used first by A. Cornu in 1873. He does not describe the apparatus, however, until ten years later ('Sur un spectroscope à grande dispersion,' *J. de Phys.*, 1883 (2), *2*, pp. 53–57). The first suggestion of such a device seems to have been made by Mascart ('Recherches sur le spectre solaire ultra-violet, et sur la détermination des longueurs d'onde,' *Ann. école norm.*, 1864, *1*, pp. 219–272). See also S. P. Langley, 'The Selective Absorption of Solar Energy,' *Amer. J. of Sc.*, 1883 (3), *25*, pp. 169–176, *Philos. Mag.*, 1883 (5), *15*, pp. 153–183, *Ann. Chim. et Phys.*, 1883 (5), *29*, pp. 497–542, *Wied. Ann.*, 1883, *19*, pp. 226–244, 384–400; B. B. Donath, 'Bolometrische Untersuchungen über Absorptensspectra fluorescerender Substanzen und ätherischer Oele,' *Wied. Ann.*, 1896, *58*, pp. 608–661; and F. L. O. Wadsworth, 'Fixed-arm Spectroscopes,' *Philos. Mag.*, 1894 (5), *38*, pp. 337–351.

tively the collimator and objective arms which are fastened to the stem of the spectroscope independent of the prism table; *TD* represents an arm fastened to the prism table in such a position as to be continuous with the radius of the table which bisects the refracting angle of the prism; *AE* and *BE* represent two rods of equal length which connect *PA* and *PB* at points equidistant from the center of the table to a collar which is free to play back and forth along the arm *TD*. *M* is a micrometer screw with a graduated cylindrical head, which is used to move the collimator arm through the small angles needed to give the change of wave-length. Opposed to this screw is a plunger *p* working against the spring in the case *C*. When the screw advances it moves the collimator arm forward and when it recedes the collimator arm is made to follow it by the push of the plunger *p*. The screw and plunger are supported by a curved arm coming off from the stem of the spectroscope, which can be clamped rigidly in any position which may be desired. This arm ends in two right-angled extensions, one of which carries the screw and the other the plunger. Between *X* and *Y*, the vertical arms of these extensions, the collimator arm is moved to give the change of wave-length. The micrometer screw passes through a fixed sleeve *S* graduated in fortieths of an inch. As the screw advances the cylindrical head telescopes on the sleeve *S*, one of the graduated spaces being traversed with each complete turn of the screw. The forward end of the cylindrical head is bevelled and on the circumference of the bevelled edge is a scale of equal divisions graduated in twenty-fifths of an inch. By means of this scale and the scale on the sleeve *S*, the advancement of the screw can be read in thousandths of an inch.

That minimum deviation is given automatically by this device to all the wave-lengths falling on the analyzing slit may be understood from the following considerations. In attaining minimum deviation the incident and emergent rays make equal angles with the normal to the refracting faces of the prism, therefore equal angles with the refracting faces themselves. When an adjustment is made for minimum

deviation for the D-line of the spectrum, for example, and the wave-length is changed by moving either the collimator or objective arms, the prism must be turned through half the angle through which the collimator or objective arm is moved if the wave-length traversing the axis of the objective tube is to be deviated the minimum amount. That is, for the prism to be set for minimum deviation the line bisecting the refracting angle of the prism will also bisect the angle made by the incident and emergent rays; hence if in changing the wave-length, the angle between the incident and emergent rays be changed a given amount by a movement of the collimator or objective arm, the prism must be moved through half that angle in order that the line which bisects its refracting angle will also bisect the angle made by the incident and emergent rays. The special purpose of the attachment described above, therefore, is to turn the prism through half the angle traversed by the collimator arm in changing the wave-length. This is attained by placing the prism on the table so that the radial arm *PD* bisects the refracting angle, and by connecting the moveable collar on the arm *PD* with the collimator and objective arms at points equidistant from the center of the prism table by rods of equal length (*AE* and *BE* of Fig. 4). Then when an adjustment is made for the D-line, and the collimator arm is moved through the angle needed to change the wave-length which falls on the analyzing slit, the arm (*PD*) turns through half that angle and takes up a position midway between the collimator and objective arms, and the part of the spectrum which falls on the analyzing slit is deviated the minimum amount in passing through the prism.[1]

[1] A constant deviation prism may be used also for getting automatically minimum deviation for all parts of the spectrum. Such a prism may be constructed by setting two 30° prisms against the faces of a right-angled totally reflecting prism; or the prism may be made in one piece in such a way that the four vertical faces enclose four angles of 90°, 75°, 135°, and 60° respectively. In using this type of prism the collimator and objective tubes are set permanently at right-angles to each other. When this is done and the prism is rotated about a vertical axis, the different portions of the spectrum are thrown on to the analyzing slit and the portion that enters it at any moment, will traverse the system at minimum deviation.

In the early part of our work we used a constant deviation prism of the Cassie

Following is a description of the parts and mounting of the spectroscope. The collimator slit (S_1) is 12 mm. long. Its width is adjusted by means of a micrometer screw fitted with a head graduated to read thousandths of a mm. The collimator lens (*CL*) is a Zeiss triple achromat, 180 mm. focal length, 60 mm. diameter; the objective lens (*OL*) is also a Zeiss triple achromat, 240 mm. focal length, 60 mm. in diameter. The prism (*P*) is 100 mm. high and has a refracting base of 85 mm. and a refracting angle of 60°. Owing to the large size required, a liquid (CS_2) prism has thus far been used. With the exercise of a reasonable amount of caution to keep the CS_2 free from impurities, this prism has given very good satisfaction. At present we see no good reason why its use should not be continued. The analyzing slit (S_2) is made adjustable in length. The range attainable varies from 0 mm. to 12 mm. A slit adjustable in length is employed in order that the amount of light entering the eye may be made independent of the natural pupillary aperture. (See 'A Substitute for an Artificial Pupil,' *Psy. Review*, 1916, —, September number.) So far it has been mounted on an independent base screwed to the table in a fixed relation to the base of the spectroscope and the stimulus-opening in the campimeter. If desired this base might be made a continuation of the base of the spectroscope. In order that the distance of this slit from the objective lens (*OL*) may be adjusted for the different focal distances for the different wave-lengths, the frame in which the slit is mounted is furnished with a rack and pinion adjustment.

In Figs. 2 and 3 is shown the mounting of the spectroscope. At *E* may be seen the platform and track on which moves the carriage bearing the spectroscope. The platform is supported on four upright somewhat pointed screws (F_1) which serve the triple purpose of leveling the apparatus, of

type which not only gives automatically minimum deviation but also the effect of a train of prisms; *i. e.*, the arrangement is such that the light is passed back and forth through the prism a number of times before it finally enters the objective tube. (Cassie, W., 'Multiple Transmission Fixed-arm Spectroscopes,' *Philos. Mag.*, 1902, Ser. 6, *3*, 449–457.) This prism was constructed to special order of the dimensions needed for our apparatus.

allowing an adjustment of 4 inches in height, and of preventing chance shifting of the position of the apparatus on the table.[1] To this movable platform is securely fastened the heavy stem and tripod base on which the spectroscope is mounted. The prism table of the spectroscope is shown at *W*. It has two adjustments. (*a*) With its supporting table it can be rotated in the horizontal plane to provide for the adjustment of the collimator and objective systems at the angle of minimum deviation and to allow for change of wave-length by the rotation of the prism if that should be desired. And (*b*) it is furnished with three leveling screws (F_2) by means of which it can be accurately leveled. The collimator and objective tubes are mounted on two horizontal arms (D_2 and D_3) which rotate about the upright stem on specially prepared collars. D_2 furnishes the support for the light source and the collimator tube, and D_3 for the objective tube. In order that these arms when adjusted shall be

[1] In the construction of the carriage and track great care was taken that there should be no play or free motion of the parts. This was necessary in order that for a given reading of the Vernier scale on the carriage and platform the axis of the objective should always sustain the same relation to the slit (S_2)—in other words that for a given reading the same wave-lengths should always fall on the slit.

The calibration of this Vernier scale was accomplished by means of a Hilger direct vision spectrometer which has a scale reflected across the upper half of the spectrum. Since wave-lengths can not be read directly from this type of instrument, a supplementary chart must be made in which are given the values of the different scale divisions in terms of wave-length. This was done as follows. Twenty-six points in this scale were identified with the bright lines given by potassium, strontium and cadmium arcs and by the mercury tube. The wave-lengths of these bright lines were obtained from Hagenbach and Konen's 'Atlas of Emission Spectra,' and from these values the curve of wave-lengths was plotted for the entire spectrum. For the calibration of the Vernier scale the Hilger spectrometer was then mounted behind the stimulus-opening in the campimeter screen, and the wave-lengths coming through for any given reading of the Vernier scale were determined.

The calibration of the graduated scale on the fixed sleeve and cylinder head of the minimum deviation attachment (p. 258–260) may be accomplished in a similar way.

In case the minimum deviation attachment is used and the changes of wave-length are produced by it, such precision in the construction of the carriage and track as is described above is of course not necessary. That is, the carriage and track, while devised in our particular apparatus primarily for changing the wave-length, is very serviceable for other purposes which do not require such careful construction. For example, we have found this feature to be very useful in lining up the instrument with other apparatus, especially when the work requires the objective arm to be fixed as is needed in our adaptation of the spectroscope to the campimeter.

held rigidly in place, they are firmly clamped to the supporting table by means of the metal pieces (G_1 and G_2) one end of each of which is milled down to fit in a groove in this table (H) and the other is clamped respectively to the arms (D_2 and D_3). The collimator and objective lenses are each mounted in brass telescope tubing provided with a rack and pinion for the adjustment of its length. In order that the axes of these tubes may be in the same horizontal plane the following provisions for leveling are made. The tubes fitted about one-fourth of their length from the larger end with collars (I_1 and I_2), are swung on trunions (J_1 and J_2) in U-shaped housings (K_1 and K_2) supported by small vertical pillars coming up from the horizontal arms (D_2 and D_3). The smaller end of each tube rests on a leveling screw (F_3 and F_4) threaded in a short horizontal stem coming out from the housings (K_1 and K_2), by means of the adjustment of which the axis of the tube may be brought into the proper position. When this position is attained provisions are made for clamping the tube firmly in place. In order that room may be allowed between the prism and the collimator and objective tubes for the introduction of apparatus for reducing the intensity of light or for any other purpose that may be desired, the vertical pillars carrying the tubes run in slots 10 cm. long cut in the horizontal arms (D_2 and D_3). When adjusted to the proper position the pillars are firmly clamped to the horizontal arms by means of the milled nuts (M_1 and M_2). The analyzing slit to separate out the wavelengths to be used for the colored stimulus is shown at S_2. The length of this slit may be made to vary from 0 mm. to 12 mm. Its width is adjustable by means of a micrometer screw fitted with a head graduated to read to thousandths of a mm. This slit is mounted vertically in an oblong brass frame, 12 cm. long and 6.5 cm. broad, carrying on each side a groove. In this groove slides a narrow brass plate on which is mounted a linear thermopile (T) with its receiving surface facing in the direction of the slit through a circular opening in the plate. During the color observation the plate and thermopile are raised out of the path of the beam of light

and clamped. For the energy measurements they are lowered to the level of the slit. In order to focus the different wave-lengths of the spectrum on the analyzing slit, a micrometer adjustment is provided to regulate the distance from the objective lens. The frame for thermopile and slit and the micrometer attachment are carried by an upright (A_2) which is mounted to one side of the path of the beam of light on a heavy independent tripod base screwed to the table. In order that there may be an adjustment of height, the upright consists of a tube 34 cm. long fitted at its upper end with a collar and set screw into which slides a steel rod (N_1) 38 cm. in length. The micrometer adjustment consists of a tube 30 cm. long and 15 mm. in diameter along the axis of which runs a finely threaded screw fitted with a milled head. In this tube is a beveled slot 5 mm. wide and 22.5 cm. long exposing the threaded screw. Telescoping the tube are two sections of tubing of larger bore (Q_1 and Q_2), 4.5 cm. in length, to the inner surfaces of which are screwed threaded pieces which extend down into the slot and engage the micrometer screw. As the micrometer screw is turned, these tubular sections move slowly along the screw. They are each fitted with collar and set screw which hold the horizontal rods supporting respectively the framework for the thermopile and the holder for the collimating lens (L_1). The collimating lens (L_1) is inserted in the path of the beam of light in order that the light emerging from the analyzing slit (S_2) may enter parallel the focusing lens (L_2) in front of the stimulus-opening in the campimeter screen. This lens has a diameter of 40 mm. and a focal length of 140 mm. Obviously if it is to act as a collimator for all the waves of light emerging from the slit (S_2), its distance from the slit must always be kept equal to its focal length. That is, when the distance of the slit from the objective lens is changed to accommodate for the difference in focus for the different wave-lengths of light, the distance of the lens (L_1) must also be changed by an equal amount and in the same direction. This is accomplished by the micrometer adjustment described above. That is, the tubular sections which carry respectively the framework

for the slit and the holder for the lens are both operated by the same micrometer screw, hence any movement of the slit is accompanied by a similar movement of the lens. An adjustment of the distance of the lens for the slit, once made, need not, therefore, ever be disturbed in the process of accommodating for the difference in focus for the different wave-lengths of the spectrum.

In order that all stray light either from the general illumination of the room or by reflections from the Nernst glower be eliminated, the spectroscope and lens system are enclosed from just in front of the Nernst to the campimeter screen in a light-tight compartment. So far we have found it most convenient to make this compartment of light-proofed fabric. That is, the compartment must be made large enough to enclose all of the auxiliary reduction and adjusting apparatus, the thermopile, etc., and must permit of easy entrance for the purpose of making the adjustments and settings required. The construction of a compartment having these requirements we found could be most simply and feasibly accomplished by employing, as stated above, light-proofed fabric. There are so many ways in which such a compartment can be constructed that space will not be taken here for a description of the compartment we have used. It will be sufficient to say that adequate care has been taken to exclude any stray light that might find its way into the stimulus by means of reflections and refractions within the system.

It is well known to spectroscopists that if some portion of the spectrum obtained by a single spectroscope be examined by a second instrument of good resolving power, frequently more than one band will be obtained. For example, if a spectroscope is so adjusted that only a narrow region of the red falls on the objective slit and the light emerging from this slit is passed through a second spectroscope, it may be found that the second resolution gives one or more comparatively faint bands in some other part of the spectrum. In most cases where a good instrument is used this degree of impurity would probably not appreciably change either the radiometric or optical results. However, we have endeavored to

devise means whereby light of such a degree of purity may be obtained that the second resolution shows only the one band. Our first step in this direction was (*a*) to eliminate as far as possible all stray light and internal reflections. Stray light was eliminated by carefully light-proofing the housing of the apparatus. Also the base of the prism and every other surface which might either admit or reflect extraneous light into the path of the refracted beam was blacked. Some of the harmful sources of internal reflection were found to be the bounding surfaces of the objective lens, the prism faces and the analyzing slit, principally the surfaces of the lens.[1] For example, in looking into the forward end of the objective tube a number of small images of the spectrum can be seen graded in size and nearly in line but projected to different distances. These images show of course that light is being reflected back and forth in the optical system. The amount of this reflection can be lessened to a considerable extent by reducing the area (cutting out the edges) of the lens and prism surface exposed to the beam of light. However, since this method of reducing the amount of internal reflection lessens also the intensity of light, only a limited use was made of it. If care is not taken to prevent it, light from neighboring regions of the spectrum will also be reflected back into the objective tube from the surfaces on either side of the analyzing slit. These surfaces should, therefore, be very carefully blacked. Some good perhaps is accomplished by slanting them slightly so that the edges of the slit point in the direction from which the light is coming. The effect of this is to reflect out of the system all light but that which passes through the slit. The edges of the slit also require careful attention if reflections are to be avoided. The knife-edge should not be obtained by a steeply pitched bevel on either side. We have found that very satisfactory edges may be made from sections of Gillette razor blades. (*b*) A minimum deviation device was attached to our spectroscope (see pp. 258–260). This was found to add a great deal to the

[1] The surfaces of this lens being concave on the side opposite to which the light enters the lens tend to reflect the parallel waves toward the axis of the beam, and thus again to mix the light which had been resolved by the prism.

purity of the spectrum.[1] But (*c*) the simplest and most effective device proved to be the use of thin gelatine filters especially selected with reference to the bands that were to be eliminated. The use of these filters in fact is enough to give the desired purity even when no other precautions are taken. Moreover, we were able to select these filters so that there was so little absorption of the light that we wished to use as to be of no consequence for the purposes of our work. They were mounted in an especially constructed holder between the objective tube of the spectroscope and the analyzing slit. A similar result could be accomplished by using two spectroscopes in series.[1] But the expense and inconvenience of doing this make it undesirable in work of the type we are doing, more especially when the desired purity can be obtained by the simple means described above with probably a negligible reduction of the intensity of the useful light.

Apparatus for Varying the Intensity of the Stimulus Light

In designing an apparatus which will be at all broadly serviceable in the investigation of color sensitivity, due

[1] Our attention was called to the effect of the minimum deviation by the observation that when the prism was adjusted for minimum deviation for the D-line and the wave-length was changed by shifting the spectroscope by means of the driving screw shown in Fig. 2, the farther the D-line was from the analyzing-slit, the greater were the number of bands which appeared in the field when the light emerging from the slit was examined by means of a second spectroscope. Without the use of the gelatines or a second spectroscope, however, we have not been able to get rid entirely of the bands mentioned above.

[1] It is obvious that an advantage is gained here for purity over and above the increase in resolving power given by two prisms. Increase in resolving power is usually gotten by using a train of prisms in a single spectroscope or a single prism through which the light is passed more than once. (The Cassie prism used earlier in our work is of this latter type, see this paper, footnote, p. 260.) But while increasing the resolving power increases the purity of the spectrum (Schuster, 'Theory of Optics,' p. 163 expresses the dependence of purity on resolving power by the formula $P = pR$, where P represents purity; R, resolving power; and p, a factor which is a function of the slit-width), the impurities caused by internal reflections are clearly of a kind that can never be eliminated entirely by an increase of the resolving power of the prism or train of prisms. This, so far as we know, can be done only in ways similar to those described above. The use of a second spectroscope, however, besides being much more expensive and more inconvenient to manipulate, causes a greater decrease

attention should be paid to adequate means of varying intensity. This has become of especial importance because of the growing recognition of the usefulness of the threshold and just noticeable difference determinations as the basis of comparative work. We have designed, therefore, apparatus to produce both gross and fine changes in the amount of light employed, more especially the small gradations

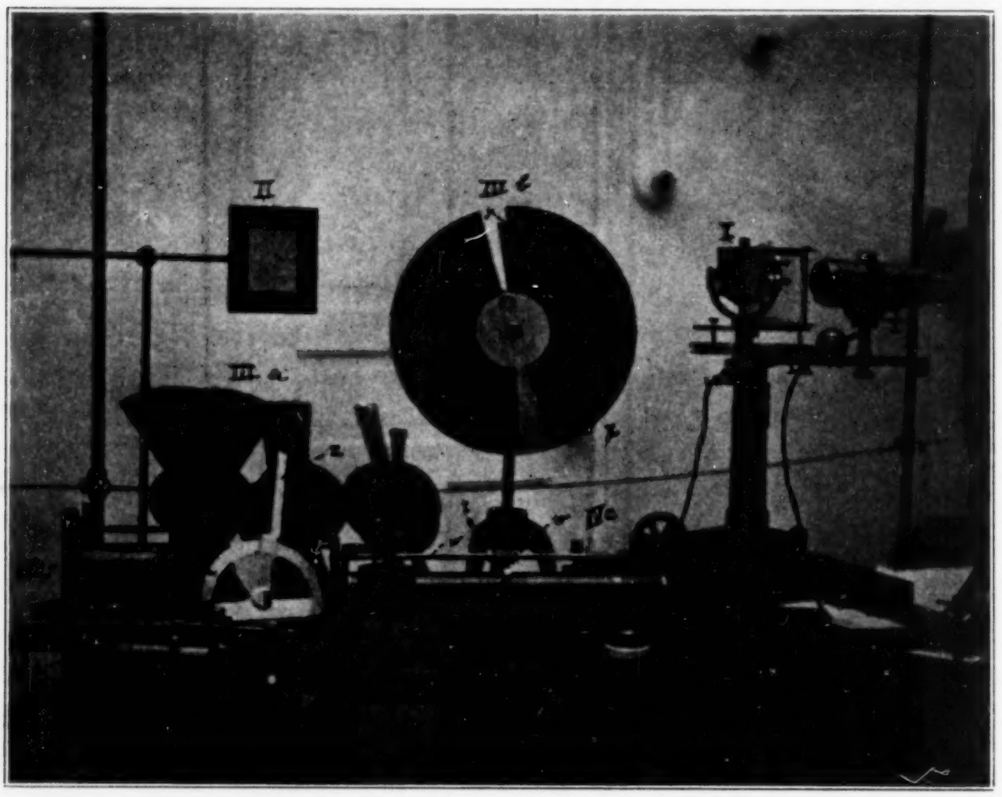


FIG. 5. Showing Auxiliary Apparatus Designed for the Reduction of the Intensity of Light—specially constructed resistance coils, coarse grating, aluminum sectored discs with Vernier protractor, and collimator slits including just noticeable difference slit.[1]

needed for threshold and just noticeable difference determinations. This apparatus is shown in Fig. 5. It consists

in the intensity of light used as stimulus than do the filters mentioned above, which when properly selected may produce practically no change in a given region of the spectrum and absorb heavily in other regions.

[1] In III. *b* the disc made up of a single 15° sector (*x*) is shown bright side before to make it distinguishable from the remainder of the compounded disc. When in use it is placed behind the other discs and the black side is turned towards the focusing lens just behind the stimulus-opening.

of (1) two types of collimator slit, one of which is especially devised for just noticeable difference work; (2) coarse gratings designed to give gross variations in the intensity of light; (3) sectored discs suitable for threshold and just noticeable difference work in which all of the changes from 0°–348.75° total aperture may be made, and a protractor with Vernier scale to permit of close reading of the discs especially when the aperture is small; and (4) special resistance coils designed to vary the intensity of light at the source.

Collimator Slits.—One of these slits is of the usual type having carefully beveled knife-edged jaws 12 mm. long, with a micrometer adjustment of width graduated to thousandths of a mm. Such a slit may be used (*a*) to make a reduction of the spectrum as a whole or of any part, and the reduction may be computed directly from the slit width provided the source is uniformly luminous over the surface exposed; or (*b*) one part of the spectrum may be made in turn to sustain, within limits and under the conditions mentioned above, any ratio that may be desired to any other part of the spectrum, providing the original intensities from which the reductions are made, are known. This slit, however, is not adapted to just noticeable difference determinations for a given color or range of wave-lengths. The second slit (shown at *I*, Fig. 5) is especially designed for just noticeable difference work. This slit is constructed so that its upper and lower halves are independently variable in width. It was designed especially for some new methods we are using for a quantitative comparative determination of the retina's inertia to the different wave-lengths of light in which just noticeable differences are employed. In the short exposures used in tracing the sensation from the threshold to its maximum, it is obvious that the sectored disc could not be employed in making the variations needed for just noticeable differences. While designed to meet this special need we have found it to be a very convenient means of making the variations needed for much of the general work in just noticeable difference determinations. The slit is formed by three knife-edged jaws. That is, one jaw of the slit is made

in one piece and is 12 mm. long; the other jaw is made in two pieces, each 6 mm. long. One edge, the upper for the upper jaw and the lower for the lower jaw, is beveled to fit into a dovetailed guide cut in the frame. The other edge of each jaw is held in place by a slender close fitting key of appropriate length. The jaw, 12 mm. long, is stationary and the other two jaws are made to move away from it by two independent micrometer screws operated by drum heads graduated to thousandths of a millimeter. In operation the source is adjusted so that one edge of its equally luminous surface is flush with the stationary jaw and the other jaws are pulled away from it exposing as desired different widths of this surface. In a just noticeable difference series one half of the slit is held constant and the other is varied to give the just noticeable difference. When the width of slit needed for this is obtained, that half of the slit is held constant and the other is varied, and so on until the series is completed.

The Coarse Grating.—This device is serviceable for gross reductions of the spectrum as a whole. It is shown at II. in Figs. 5 and 2. The grating consists of an exposed photographic plate ruled on a dividing engine with lines 60 to the centimeter. The gelatine side of the plate is covered with a thin glass plate and the whole is mounted in a brass frame supported by a slender rod running parallel to the lines of the grating. This rod fits into a collar furnished with a set screw so that the grating may be rotated any amount that is desired about the axis of the rod. When interposed in the path of the light this grating allows the maximum amount of light to pass through when it is perpendicular to the path. As it is rotated, less and less light gets through the open spaces afforded by the lines, the amount depending upon the angle of rotation. If it were wanted to use this grating as a more precise instrument of reduction, it would be comparatively simple to add a graduated scale so that any previous setting might be reproduced, and to calibrate the scale so that the amount of reduction might be read directly from it. So far in our work we have not felt the need to do this as the grating has been used only in making gross reductions in the amount

of light employed, the finer changes being made either by the slit or by the sectored discs. This grating may be mounted anywhere in the path of the light from the source to the campimeter screen. Thus far we have found it most convenient to insert it between the collimator and the prism (see Fig. 2).

The Sectored Discs and Vernier Protractor.—Probably the most convenient and widely applicable apparatus for varying the intensity of light by known amounts is the sectored disc. A strong objection to the use of the sectored disc when fine changes are needed such as are required, for example, in threshold and just noticeable difference work, is the difficulty of getting and of measuring accurately sufficiently small amounts of change. Such discs are ordinarily constructed with two or more open sectors, and a change in one is multiplied as many times as there are open sectors. Moreover, an error made in the measurement of one sector is multiplied by the number of open sectors. This latter difficulty becomes especially significant in working with intensities at or near the threshold when a small error may represent a high percentage of the total open sector. We have sought to overcome these difficulties in two ways. (1) Our discs for a low total aperture are so constructed that one sector may be varied at a time. And (2) a special protractor has been designed fitted with a movable arm carrying a knife edge and Vernier scale graduated to read to 1/60 of a degree.

Two sets of discs were made in all—one for simple reductions and threshold work, and the other for just noticeable difference determinations. The discs were cut from hard sheet aluminum No. 20 B. & S. gauge, 0.9 mm. thick; and are for the first set 19.5 cm. in radius. In order to give a wide range of change a number of discs are required. For example, a variation of total range of open sector from 0°–348.75° is obtained in the first set of discs by using four pairs of two-sector discs and one pair of one-sector discs with a counter-balancing weight. In the first pair the breadth of each of the two open sectors is 90°, and the range of variation

of total open sector is from 0°–180°; in the second pair the breadth of each of the two sectors is 45° and the range of variation of total open aperture is from 180°–270°; in the third pair the breadth of each of the two open sectors is 22.5° and the range of total aperture is 270°–315°; in the fourth pair the breadth of each of the two sectors is 11.25° and the range of total aperture is 315°–337.5°; and in the fifth pair the breadth of the single sector is 11.25° and the range of total aperture is from 337.5°–348.75°. In order that very small apertures may be obtained or that small variations of aperture may be had, when each open sector is 15° or less, a small single sector furnished with counterbalancing weight was provided in addition to the five pairs of discs. When this is used with the pair of discs having 90° sectors to cover one of the open sectors, the total aperture may be varied from 0° through 15°. This single sector may also be used in connection with any of the other pairs of discs to aid in making smaller variations in the total aperture than is obtainable with the pair of discs alone. That is, as one of the open sectors is opened, the other may be closed by any desired amount less than 15° by means of this single sector. Following this principle broader single sectors may be constructed to permit of smaller variations when the total aperture is still larger. We have found, however, that the 15° sector satisfies the need for the values of total aperture for which small changes are significant.[1]

In order to make the first set of discs serve also for just noticeable difference determinations, it was necessary to supplement each of the pairs of discs in this set with single discs of the same breadth of sector and of lesser radius.

[1] In the construction of these discs a solid disc with a radius of 19.5 cm. was first cut from a sheet of aluminum. The open sectors were then cut into these discs of the breadth desired to a depth of 13.5 cm. This left a small solid disc of 6 cm. radius to support the pairs of sectors. As was stated above in order to guarantee symmetry of rotation in case of the single sectors, a counterbalancing weight was fastened on the opposite side from the sector 6 cm. from the center of rotation. This weight was in the form of a small lead disc soldered to the inside supporting disc in line with the radius which just bisects the sector. It is scarcely needful to say that great accuracy is demanded in the cutting of the discs. This accuracy was obtained by means of a special cutter designed for cutting with accuracy straight and curved edges in metal.

These discs were 17 cm. in radius and the open sectors were cut in from the outer edge to a depth of 11 cm. A margin of 2.5 cm. was thus left between the edges of the two sets of discs. In making the just noticeable difference determination the two sets of discs are adjusted so that the edge of the inner disc just bisects the stimulus-opening. The openings of the two sets are then varied independently as may be required, it being necessary of course always to make the open sectors of the outer discs the larger. The sectored discs are shown at III. *a* in Fig. 5. The method of using them is further illustrated at III. *b*. Here the discs are shown mounted on an electric color mixer and are set for a just noticeable difference determination low in the intensity scale. Two of the set of larger discs each having two 90° sectors are mounted to give two open sectors one of which is closed by means of the single 15° sector shown at *x*, leaving a total aperture of 10°. In front of these is mounted the disc of smaller radius with the edge of one of its sectors shown at *y* projecting 4° into the 10° opening reducing it to 6°. When the disc so compounded is adjusted in front of the stimulus-opening so that the edge of the disc of shorter radius just bisects this opening and the disc is rotated at the fusion rate, the two halves of the opening are illuminated with light of intensities proportional respectively to 10 and 6. By using the discs of different breadths of sector, similar variations can be achieved over a range 0°–347.75° open sector.

The special protractor by means of which the width of the open sectors may be read to 1/60 of a degree is shown at Z. This protractor is provided with a 180° arc of 10 cm. inside radius, and an arm 27 cm. long which rotates about a central collar closely fitting the chuck of the motor. The 180° arc is graduated to 1/4 degrees and the movable arm carries a Vernier scale graduated to 1/60 degrees. The movable arm carries a beveled slot also of a 10 cm. radius of curvature into which the 180° arc fits. To insure accuracy of setting this movable arm is provided with finely beveled straight edges. When making a measurement of open sector, one of these edges is set flush with one of the edges of the sector

and the reading made. It is then rotated until the same edge is flush with the other edge of the sector, and the difference between the readings is taken as the value of the sector. We have thought it necessary to stress the accuracy with which these measurements must be made because the threshold value of sensation is frequently obtained for the intensities of light employed by us with a total aperture of 1/15°. With such small apertures it is obvious that accuracy of measurement becomes of prime importance. When used in connection with the spectroscopic apparatus described in a preceding section to determine the threshold and just noticeable differences in sensation, the sectored discs are interposed in the path of the parallel beam of light just behind the lens L_2 (see Figs. 2 and 3). As is shown in this figure in order to eliminate as far as possible all vibrations and consequent displacements of the edges of the discs from the desired alignment with the beam of light, the discs are mounted on a motor (*S*) suspended by springs. With discs so designed and used, and with the proper standardization of the factors which influence the response of the eye, determinations may be made having a very high degree of reproducibility.

Special Resistance Coils.—Special resistance coils have been devised which serve the following purposes: (1) to give the fine changes of resistance needed to compensate for fluctuations of voltage in the lighting circuit which otherwise might produce troublesome variations in the flux of light from the Nernst filament; (2) to produce changes in the intensity of the spectrum given by the filament;[1] and (3) to make possible the fine changes in the speed of rotation of the discs that are so frequently required in work in the optics of color. These coils are of two general types. (*a*) Coils which give fine changes over a narrow range; and (*b*) coils which will permit of fine changes over a wide range. Coils of the first type are shown in Fig. 5 at IV. *a* and *b*; a coil of the second type at IV. *c*. The resistances of the first type consist of one coil and are constructed to give the effect of a

[1] It was recognized of course in using the resistance for this purpose that a change in the amount of current by which the Nernst is operated changes the spectro-radiometric composition of the light.

contact sliding along a single wire. The effect is produced by winding the coil of wire of the desired size and resistance on a hollow brass cylinder insulated with micanite, and by turning this coil by means of a screw motion under a U-shaped contact. In this way the contact is made to travel along the entire length of the wire, and the fineness of change is limited only by the size and coefficient of resistance of the wire. In one example of this general type of resistance shown in Fig. 5 (IV. *a*), the contact is kept stationary and the cylinder is mounted on a rod as its axis, threaded at both ends. As this rod operated by a milled head turns, the cylinder rotates and slowly advances, so that the contact travels continuously over the whole length of the wire. In a second example of this type, shown at IV. *b*, the contact slowly advances as the cylinder is rotated, and passes continuously over the whole length of the wire. This effect is accomplished as follows. The cylinder is mounted on a horizontal rod turned by a geared wheel 5 cm. in diameter. The contact is mounted on a threaded rod which is turned by a geared wheel of the same diameter as the wheel which turns the cylinder. As the latter wheel turns, its teeth engage the teeth of the wheel which rotates the rod on which the anchor piece of the contact is threaded, and the contact advances along the rod at a rate which keeps it continuously in touch with the wire throughout its whole length. The coil which we use to control the amount of current operating the Nernst filament is made of No. 26 wire, 47.8 ft. long, and has a resistance of 55 ohms.

The resistance of the second general type consists of two coils in series, one designed to make gross changes and one to add fine changes to it for any given setting of the contact. The wire of the first coil is wound on a long section of brass tubing insulated by micanite. This tube was given a stationary mounting and the changes in resistance are produced by a sliding contact shown at *v*. The supplementary coil was wound on a brass drum shown at *w*, insulated by micanite and mounted on a vertical threaded rod operated by a small wheel. As this wheel is turned the drum rotates and

slowly changes its level bringing every point on the wire successively in touch with a stationary contact. The connections are so made in this rheostat that by means of a double-pole switch shown at *t*, the poles of the large coil can be reversed and a high rate of speed can be instantly changed to a low rate of speed, and *vice versa*. In the rheostat shown in Fig. 5, the large coil is made of Advance wire No. 26, 139 ft. long, and has a resistance of 160 ohms. The small supplementary coil is made of wire of the same composition, No. 26, 17.4 ft. long, and has a resistance of 20 ohms. By means of these two coils changes of resistance amounting to very small fractions of an ohm can be made and the speed of rotation of motors of the type constructed by the C. H. Stoelting Co., for example, can be controlled to fractions of a revolution per second. We have found such control to be very useful in the general field of work in which impressions are to be g ven to the eye in succession, and especially necessary in the studies that we have made of the factors that influence the results obtained by the method of flicker for the photometry of lights of different color. It is obvious that some such control must be had if the phenomena produced by changing the rate at which impressions are given to the eye are to be studied in satisfactory detail.

The Rotary Campimeter

In a previous paper[1] a rotary campimeter was described especially devised for use with pigment papers. At that time it was stated that this apparatus had also been adapted for use with a spectroscope, and that a description of it would be given in a later paper. The apparatus we shall here describe has been in use, therefore, for three years and its feasibility has been tested for that length of time both in the research and drill work of the laboratory.

The object of the rotary campimeter is to add to the vertical campimeter the rotary features of the perimeter, and thus to allow investigation of every possible meridian of the retina

[1] C. E. Ferree, 'Description of a Rotary Campimeter,' *American Jour. of Psychol.*, 1912, *23*, pp. 449–453.

with as much ease and precision as was possible with the old form of campimeter in the nasal meridian only, or at most in the nasal and temporal meridians. As designed for use with the spectroscope this apparatus consists of two parts with appropriate supports and accessories: camp meter screen and lens to focus the light on the pupil of the eye and to shift the image to follow the pupil as it takes an excentric fixation; and attachment to line up the eye with the stimulus-opening. The campimeter screen rotates on a brass collar around a circular support. The stimulus is exposed through an opening in the center of the campimeter screen. Behind this opening mounted in a smaller brass collar is the focusing lens (L_2). This lens is carried on a rack and pinion which moves its center back and forth along a line which passes through the center of the stimulus opening and which contains all the fixation points on the arm (I–I').

Fig. 6 shows the skeleton apparatus. It consists of the following parts: supporting base, frame for campimeter screen,

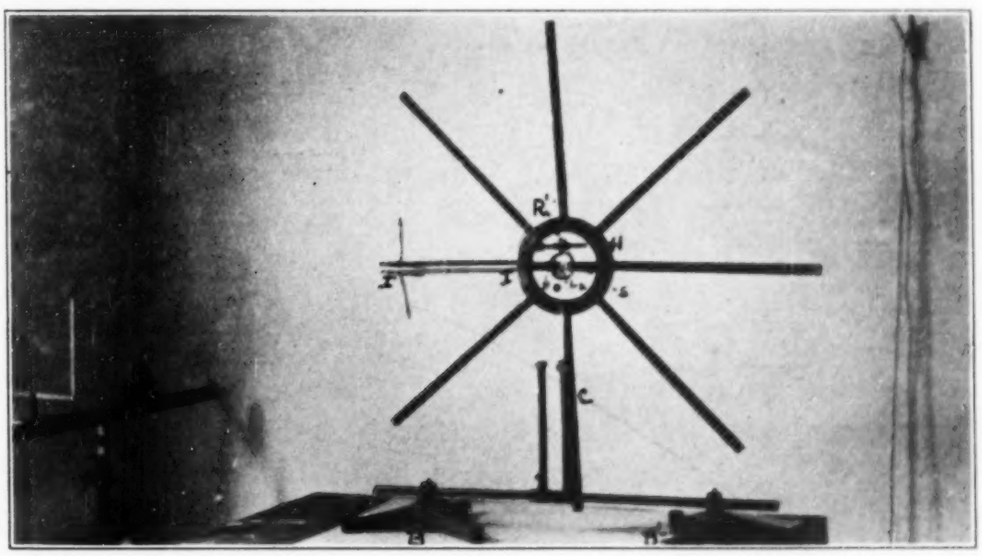


FIG. 6. Showing the Rotary Campimeter, the Lens for Focusing the Light on the Eye, and the Rack and Pinion used to shift the focal point as the eye changes its fixation.

rack and pinion adjustment and support for the focusing lens, and attachment for lining up the eye with the stimulus-opening. The supporting base consists of a horizontal steel

bar, 83 cm. long, supported by two tripod rests (*B* and *B'*). To this bar is clamped an upright (*c*) which serves as a support for the framework of the campimeter screen. In order that the distance of the upright of the screen above the table may be adjustable, this upright consists of a steel tube 27 cm. long and 15 cm. in diameter furnished at its upper end with a collar and set screw into which fits a rod 20 cm. long, to which the framework of the campimeter screen is attached. The framework of the campimeter screen consists of a stationary brass ring about which rotates a larger brass collar (*H*), 20 cm. in diameter.[1]

The back circumference of collar (*H*) is graduated from 0°–360°. To this collar are fastened the radiating arms. There are eight of these arms, one for each 45° mark on the graduated collar. They are made of steel and are 2 cm. broad and 40 cm. long. The eighth arm (*I–I'*) differs from the other seven. It forms a right angle, one side of which lies in the plane of the background, and the other in front of this plane. The part in the plane of the background is 60 cm. long and the part at right angles to this plane is 28 cm. long. The arm is graduated from 18°–57° along the section that lies in the plane of the background, and from 57°–92° along the section at right angles. The graduations are based on the arc of a circle of 25 cm. radius. The rack and pinion adjustment (*R'*) which carries the focusing lens is attached to the rotating collar. Thus when the arm carrying the fixation points is rotated into any given meridian, the rack and pinion adjustment is also rotated so that the line of motion of the center of the lens always contains the fixation points. The focusing lens (L_2) is a double convex lens 50

[1] This ring was made large in diameter for two reasons. (*a*) The ring had to be made thick in order to give sufficient rigidity to support the campimeter screen and to furnish the proper attachment for the rotary collar. Had the circumferance been made small, the effect of the ring would have been that of a short tube. If the stimulus were viewed through a short tube, an induction factor would have been involved which would have been difficult if not impossible to standardize. The opening of the ring was, therefore, made considerably larger than any stimulus we wished to use in order to avoid the introduction of this factor. (*b*) The large circumference of the ring makes the apparatus available for investigating the effect upon sensitivity of varying the size of the stimulus.

mm. in diameter and with a focal length of 275 mm. It moves in a plane 2.5 cm. behind the stimulus-opening, hence the parallel rays of light entering it from the collimating lens (L_1) are brought to a focus on the pupil of the eye when in position 25 cm. behind the stimulus-opening. To the eye at this point, the lens, or as much of it as is visible through the stimulus-opening, is seen uniformly filled with light. That is, it is a well-known fact in physiological optics that when parallel rays of light are focused on the pupil of the eye, or more accurately perhaps, at the optic center of the refracting mechanism, by means of a double convex lens, the lens is seen by the eye as if uniformly filled with light. As the eye takes the different fixation points on the arm (I–I') the light is kept focused on the pupil by slightly displacing by means of the rack and pinion adjustment the center of the lens in the direction in which the eye is turned in taking the new fixation.[1] The adjustment is quickly and easily made. In fact the rotary campimeter adapted to the spectroscope in the manner described in this paper presents little if any more difficulty of operation than it does when pigment papers are used as stimuli.

The device for lining up the eye with the stimulus-opening is also attached to the rotary collar (H) and is constructed as follows. A cross piece (S) 16 cm. long and 1.8 cm. wide is fastened by a screw with a milled head to one side of the collar (H) and is supported by a pin on the opposite side. A pin is used instead of a second fastening in order that the device may be conveniently and quickly turned out of the path of light when not in use. In the center of the cross piece (S) is a circular opening (O) 15 mm. wide. When in position immediately behind the opening in the campimeter screen which admits the stimulus light, the center of this opening lies in a line perpendicular to the opening in the screen at its central point. To the cross piece (S) 3 cm. to

[1] In taking a new fixation the pupil is seen to turn from under the colored image and to the observer the stimulus-opening is no longer filled with colored light. As the center of the lens is shifted in the appropriate direction, however, the image is seen to travel towards the pupil, and when it falls full upon it, the observer again sees the stimulus-opening filled with light.

the side of the opening (*O*) is fastened at right angles an arm 12 cm. long and 1 cm. wide, terminating in a disc (*P*) 2 cm. in diameter. Three centimeters from its outer end this arm is bent at right angles so that the disc lies directly behind the opening (*O*) and in a plane parallel to that opening. The size and position of the stimulus-opening, the opening (*O*), and the disc (*P*), and their distances from each other sustain such relations that when the eye is in position 25 cm. behind the stimulus-opening with the center of the image of that opening on the fovea and the line of regard normal to the plane of the opening, the edge of the opening (*O*) is just contained within the stimulus-opening and the edge of the disc is just contained within the opening *O*. That is, in effect the device is a peep sight arrangement, and the alignment described above is possible only when the eye is at the center of curvature from which the fixation points on the arm (*I–I'*) are determined. As stated above, this attachment is fastened to the collar (*H*) by means of a screw with a milled head, so that after the alignment is made it can be readily turned out of the road and clamped. In order that the distance of the eye may be adjusted at the same time as its alignment is made with the stimulus-opening, a measuring device 25 cm. long is provided. This device consists of a slender brass rod fitted at either end with two short right angled arms 5 mm. in length. On the end of one of these arms is a ring which is just larger than the stimulus-opening, and on the other is a brass disc of the same diameter as the ring, provided at its center with a pupillary aperture. In adjusting the distance of the eye the disc is rested lightly against the forward surface of the eyeball and the ring against the campimeter screen concentric with the stimulus-opening. When the position of the eye is once determined, a mouthboard is adjusted and clamped in position so that the observer's teeth fit into impressions previously made and hardened in wax. This fixes the relation of the observer's eye to the campimeter system. All that is needed, therefore, at subsequent sittings to bring the eye into this relation is again to fit the teeth into the impressions on the mouthboard.

In order to facilitate excentric fixation in the nasal and temporal meridians, the head should be turned in adjusting the mouthboard 45° nasalwards or temporalwards as the case may be. With the head so placed, the eye can swing easily from the stimulus-opening to a fixation point whose excentricity exceeds 90°.

The front view of the campimeter in readiness for use may be seen in Fig. 2 of our former paper; a back view is given in Fig. 3 of this paper. A cardboard background has been fastened to the steel arms by means of metal fasteners pushed through holes in the steel arms and clinched. Since the background is fastened to the arms attached to the brass collar (*H*), a circular gap is left at its center. This gap is filled by a disc (*N*) shown in Fig. 3, which has been fastened to the arms just outside of the collar (*H*). The disc is 27 cm. in diameter and contains the stimulus-opening (*O*), the size of which may be varied to accord with the purpose of the investigation. In order to complete the graduations on the fixation arm to the stimulus-opening, disc (*N*) is graduated from 0°–18°. A background, 40 cm. in height, is fastened to the extension arms (*I'*). This background for screen and extension arm may be covered with whatever standard paper or surface that is desired.[1] The graduations from 0°–92° are pricked in this covering at points determined by the markings on the back of the disc (*N*) and the arm (*I–I'*). These constitute the fixation points.

The method of using this apparatus is as follows. The eye of the observer is lined up with the stimulus-opening by means of the attachment described above at a point 25 cm. from the campimeter screen; and the position of his mouthboard is adjusted. With his eye in this position the lens should fill uniformly with light whenever the image of the analyzing slit falls on the pupil. Before the color observations are begun this is tested out by taking a number of

[1] In all tests of the relative and absolute sensitivity of the retina this screen should be made of a gray of the brightness of the color to be used. No departure from this rule should be permitted in tests of sensitivity unless it is for the purpose of determining the effect of different screens on sensitivity, or of using this effect as a means of varying sensitivity.

fixation points from 0° to the periphery of the field of vision and adjusting the focusing lens in each case to bring the image of the slit full upon the pupil of the eye. In making the color observation the unused eye is covered with a bandage. The arm (*I–I'*) is turned into the meridian to be investigated, the position being determined by the graduations on the collar (*H*). The experimenter inserts a card which we shall call the preëxposure card, between the eye and the stimulus-opening as near to the opening as possible while the observer takes the fixation required. In all investigations of relative and absolute sensitivity, this card should be made of a gray of the brightness of the color to be used. At a signal given by the observer the preëxposure card is withdrawn, the eye is exposed to the stimulus for the required length of time and the card is replaced in the path of the stimulus light. The observer is required to rest the eye after each observation. Further provisions against fatigue are made by frequent and regular intervals of rest.

It is often desirable to have an equation representing what is sensed at a given point in the peripheral retina in terms of what is sensed in the central retina. In this way a representation may be had for comparative purposes of the color tone, brightness and saturation for light of a given intensity and range of wave-length.[1] In the campimeter devised for use with pigment papers provisions were made for this. That is, it was possible to rotate a small disc on which the representation might be made, just behind the fixation point for all positions of the point from 0°–90° in any meridian. This disc was rotated by a small motor the shank of which protruded through a slit 8 mm. wide running the full length of the fixation arm (*I–I'*). For a further description of this motor, its supports, adjustments, etc., and the method of making the match of the sensations aroused in central and peripheral retina, see the former

[1] In making a comparative study of the sensitivity of the different parts of the retina, such an investigation is a valuable supplement to a survey of sensitivity made on the basis of threshold and just noticeable difference determinations. The two methods are needed in fact to give a complete representation of the sensitivity of the retina in its quantitative and qualitative aspects.

article, p. 452. In the rotary campimeter devised for use with the light of the spectrum no similar provision has as yet been made. The difficulties appending the attempt to get a spectrum light variable at will in intensity, color, and brightness which can be easily and conveniently presented to the eye at any point of any meridian of the field of vision are obvious at a glance. Dreher, for example,[1] was able to make a match of the sensations aroused at the center and periphery of the retina without very inconvenient changes in his apparatus for one point only in the peripheral retina. An attempt is being made to adapt our present apparatus so that this match can be accomplished conveniently for any point in the peripheral retina, but as yet nothing definite can be promised.

[1] Dreher, *loc. cit.*